GEOLOGISKA FÖRENINGENS
I STOCKHOLM FÖRHANDLINGAR

No 501

Band 82. Häfte 2. Mars—April 1960

Moränavlagringar med linser av sorterat material i Stockholmstrakten

Av

HANS MÖLLER

Sveriges geologiska undersökning, Stockholm 50

Summary: Till deposits with lenses of sorted material in the vicinity of Stockholm

Lenses of sorted material consisting of fine sand, sand and gravel are common in till deposits. In the vicinity of Stockholm a number of sections in till deposits have been studied. Most of these are located either on the stoss sides or on the lee sides of knobs of bed-rock in relation to the last ice movements.

All the sections on lee sides are characterized by the presence of till with lenses of sorted material. These deposits are complex and of various kinds. The till proper is unconsolidated and commonly includes portions of incompletely sorted material. Sorting of this till is somewhat better than on the stoss sides (figs 3 and 7). The lower percentage of fine-grained fractions shows that the material has not been transported any great distance in the ice. Many sections on the lee sides show till-with-lenses covered by real lodgement till. The latter is compact (hard packed), shows foliation and is lens-free. In all the sections on stoss sides has only the latter type of till been observed.

The genesis of the various deposits in which till-with-lenses has been found is discussed. It is assumed that the till-with-lenses at locality 1 (fig. 2) and other similar sections is due to deposition at the margin of an advancing ice sheet, the lenses of sorted material representing marginal meltwater streams. Subsequently, such deposits were shielded in some way from erosion by the ice and became progressively covered by a hard packed, foliated lodgement till.

The orientation of boulders at locality 1 (fig. 2) shows that the till-with-lenses at this locality has been deposited during an ice movement directed about S 30° E, whilst the upper part of the hard packed and foliated lodgement till has been deposited during an ice movement directed about SSW. According to the examination of glacial striae in the vicinity of Stockholm, the latter movement must be much younger than the former.

At some localities large lenses were found almost in direct contact with the bed-rock. Such may be relict from sorted sedimentary layers deposited outside the ice and later

overridden by it. At one locality (10) the sorted material was very fine-grained, hard packed and with contorted strata (fig. 11). The small portion ("boulder") of till with very fine sand and silt at locality 1 (figs 2 and 15) also shows that fine-grained sedimentary layers have been overridden and partly taken up by the ice. At other localities where overlying lodgement till is lacking, the till with lenses could have been deposited much later, for example at the ice-margin during the shrinkage of the ice. The section shown in fig. 8 is of this type, though one of the lenses here is unusually large.

A more detailed explanation of the genesis of such deposits requires consideration of the following features. 1. Dead-ice and dead-ice deposits in lee places. 2. Uplift of the ice margin in water. 3. Marginal drainage. 4. Lenses as primary or secondary deposits, in the latter case the lenses are "boulders" in the till.

In conjunction with the till deposits with lenses of sorted material on the lee sides in the vicinity of Stockholm some other groups of till deposits, in which lenses are generally met with, are discussed. These include till deposited by dead-ice, superglacial till, till deposited in conjunction with eskers and till in end moraines. Since lenses of sorted, permeable material in till can be of importance for the present-day circulation of water in the ground, the knowledge of such deposits can be of practical value.

A detail, often seen in till deposits, is a thin (1/2—1 cm) mantle of sorted sand-fine sand in direct contact with the surface of the boulders. Such mantles are assumed to have been formed in a thin layer of water between the ice and the surface of the boulders. The melting of the ice close to boulders should, in accordance with the physical theory of elasticity, be a result of an increase of pressure in the ice close to boulder surfaces.

Föreliggande uppsats bygger främst på material, som insamlats i samband med arbetet på det nya geologiska kartbladet Stockholm NO.

Moränavlagringar är så mångskiftande och kan behandlas ur så många olika synpunkter, att det ibland blir nödvändigt eller fördelaktigast att använda nya termer. Detta är bakgrunden till att jag i denna uppsats använder en ny term (lälinsmorän) samt diskuterar bruket av en annan, i Sverige vedertagen sådan (Kalixpinnmo). I anslutning till morännomenklaturfrågorna bör man uppmärksamma innebörden av termen morän i olika länder. Det svenska bruket av denna term torde vara det mest praktiska, men det kan kanske anses vara historiskt tvivelaktigt och även vilseledande för utländska läsare (Flint 1947, p. 126, not; 1957, p. 130, not). I Nordamerika, England, Tyskland m. fl. länder används termen morän vid benämning av moränens avlagringsformer, olika moränbankar (t. ex. tillhörande ett visst glaciationsskede), ännu icke avlagrad morän etc., men däremot vanligen icke vid benämning av moränjordartstyperna. Som förhållandena nu är, bör man t. ex. vid översättning till engelska använda termen till när man betecknar jordarten och termen moraine i andra sammanhang.

Det har länge varit känt, att linser av sorterat material kan förekomma i morän. Morän med dylika linser (nedan ibland kallad linsförande morän) synes vara särskilt vanlig i lälägen, sett i förhållande till de sista isrörelseriktningarna. Vid arbetet på kartbladet Stockholm NO har utpräglad linsförande morän anträffats så gott som enbart i dylika lälägen. Dessa lägesbundna, komplexa avlagringar har i denna uppsats sammanförts under beteckningen lälinsmoräner. Innan dessa beskrives, kan det vara befogat att inledningsvis i någon mån behandla linsförande morän i allmänhet.

Grus-, sand- och molinser i morän kan nästan anses som ett normalt drag i moränens inre byggnad (G. Lundqvist 1940, p. 29). Det kanske bör tilläggas, att begreppet morän då får tagas i dess vidaste bemärkelse. En kort översikt av regionala iakttagelser visar, att linsförande moräner påträffats nästan överallt i landet. I Bergslagens moräner är linserna en vanlig företeelse (l.c.). För Västerbottens län nedanför odlingsgränsen, hela Kopparbergs och hela Värmlands län gäller samma sak (Granlund 1943, p. 43; G. Lundqvist 1951, p. 56; J. Lundqvist 1958, p. 59). Vid Sveriges geologiska undersöknings regionala jordartskarteringar i Norrbotten, Gävleborgs och Jämtlands län har samma förhållande konstaterats (Fromm, G. Lundqvist och J. Lundqvist). En mängd av uppgifter om linsförande moräner finns från skilda delar av Norrland, där Sveriges geologiska undersökning utfört speciella arbeten i samband med vattenkraftens utbyggnad. I dödismorän är linser en mycket vanlig företeelse (se t. ex. Mannerfelt 1945). Från skilda delar av södra Sverige föreligger likaledes många observationer av linsförande moräner.

Linserna i moränen är i stort sett horisontellt orienterade. Enligt G. Lundqvist (l.c.) ligger de oftast konformt med markytan. De är vanligen av obetydlig storlek. Mer än metermäktiga linser med åtskilliga meters utsträckning kan dock förekomma. I speciella fall (se sid. 193) är utsträckningen i horisontell led av sådan storleksordning, att man kan tala om verkliga lager.

G. Lundqvist (1940, p. 31 och 1951, p. 32) har publicerat ett 20-tal mekaniska analyser av materialet i grus-, sand- och molinser. Dessa analyser och de i fig. 3 återgivna kan belysa, att materialet i linserna i regel är väl sorterat. Detta har otvivelaktigt sorterats av rinnande vatten. Då det gäller att närmare förklara linsernas uppträdande och bildningssätt kommer ett flertal olika möjligheter i fråga. Säkerligen är det också av flera olika orsaker som lagerföljder av denna typ bildats.

L. von Post (1929, pp. 39 f.) omnämnde linsförande, submarint bildade moränlagerföljder från västra mellersta Sverige och använde därvid uttrycket »blandad morän». Som en förklaring till dessa lagerföljder tänkte sig von Post, att isens randpartier närmast före istäckets bortsmältande mångenstädes lyfts i det vatten i vilket de slutade. I så uppkomna mellanrum mellan isen och dess underlag skulle moränmaterial ha sorterats av utåt strömmande smältvatten.

Med utgångspunkt från Bergslagens moräner utskilde G. Lundqvist (1940, pp. 29 ff.) två huvudtyper i moränens inre struktur: linser och pressningsfenomen. De förra är enligt G. Lundqvist betingade av smältvattnets verksamhet. Någon närmare förklaring till linsernas uppträdande gav G. Lundqvist ej i det citerade arbetet. Men man kan förstå, att de linsförande lagerföljderna av G. Lundqvist åtminstone till en del tänktes höra ihop med vad han kallade »intraglaciala dödisar» eller ispartier, som p. g. a. hög moränhalt fått rörelseförmågan starkt nedsatt (op. cit., p. 34 och p. 38; jfr G. Lundqvist 1957, p. 323). Dessa döda eller nästan döda partier i isen skulle ha funnits »i vissa lägen, längst ned i dalstråken, i lälägen etc.». I sådana lägen finner man enligt G.

Lundqvist den löst lagrade, icke pressade moränen. När G. Lundqvist (1951, p. 56) cirka 10 år senare berörde frågan om hur de linsförande moränlagerföljderna bildats, var han något tveksam om svaret. G. Lundqvist diskuterar två möjligheter. Antingen har materialets sortering skett ytligt eller också inuti lagerföljden (inne i isen). I det förstnämnda fallet skulle den linsförande lagerföljden ha uppbyggts av »flera bäddar eller skållor, vilka skjutits på varandra». Linserna borde dock ha varit större om lagerföljden uppkommit på detta sätt. Bl. a. av denna orsak höll G. Lundqvist det för »icke osannolikt, att sandlinserna bildats inuti lagerföljden». De skulle ha bildats »just då isskikt smält bort och korta, öppna kanaler kortvarigt stått öppna innan huvudmassan satt sig». G. Lundqvist menade dock, att det var förvånande om så korta lopp möjliggjort en så noggrann sortering och tillade därför, att denna »måste ha ägt rum tidigare, kanske på isen». I ett senare arbete, där G. Lundqvist (1958, pp. 14 f.) berör de linsförande moränlagerföljderna, nämnes icke den sistnämnda teorin om bildningssättet. Härom säges på det anförda stället endast att linserna troligen har »bildats i samband med isens framryckning över ett redan avsatt sedimenttäcke». Frusna sedimentlager skulle ha rivits sönder av isen och som brottstycken kommit in i den osorterade moränmassan.

I Värmland (J. Lundqvist 1958, pp. 59 ff.) förekommer förutom de vanliga smärre linserna större, mera uthålliga sådana ganska allmänt. J. Lundqvist antar, att linsernas större uthållighet och flerstädes rikliga uppträdande betingas av att områdets talrika, djupa sprickdalar bidragit till att öppna kanaler med smältvattenströmmar lätt uppkommit inne i isen. Enligt J. Lundqvist är dessa större linser ofta veckade, vilket visar att avsättningen skett i en levande is. Vidare urskiljer han, som en speciell typ bland de linsförande moränlagerföljderna, sådana med talrikt förekommande sandiga och grusiga linser i anslutning till supramarina isälvsavlagringar i norra Värmlands dalgångar. Mellan denna lagerföljdstyp och rena isälvsavlagringar finns kontinuerliga övergångsformer. Mäktiga och uthålliga sand- och grusinlagringar i morän påträffas särskilt i södra Värmland (J. Lundqvist l.c.), alltså i submarin bildningsmiljö. Med tanke på utbredningen håller J. Lundqvist den av von Post (1929) lämnade framställningen om bildningssättet (se ovan sid. 171) för dessa submarina avlagringar för trolig. J. Lundqvist tillägger dock, att i många fall ingår säkerligen också sediment, som avsatts omedelbart framför iskanten. Som ett ytterligare stöd för von Posts tolkning anföres, att avlagringstypen ifråga »gärna uppträder på sydänden av en höjd. Detta läge bör ha varit särskilt gynnsamt för uppkomsten av glapprum mellan isen och dess underlag».

J. Lundqvist (l.c.) betecknar den ovan omtalade moräntypen som en övergångsform mellan de linsförande moränerna och den s. k. Kalixpinnmon, alltså avlagringar som huvudsakligen utgörs av sorterade jordarter — i regel mo — vilka vid isframstötar i större eller mindre grad störts och fått materialtillskott från isen (Beskow 1935, p. 123; G. Lundqvist 1943, p. 126; Hoppe 1948, pp. 67 ff.; J. Lundqvist, l.c.). Rent allmänt kan s. k. Kalixpinnmo åtminstone ur sammansättningssynpunkt sägas stå nära de rikligt linsförande moränerna. Jag vill därför i detta sammanhang ta upp en nomenklaturfråga.

I svensk kvartärgeologisk litteratur är beteckningen Kalixpinnmo vedertagen och ofta använd. Därför kan man, trots att beteckningen av flera skäl[1] måste anses vara mindre lämplig — vid vissa arbeten direkt olämplig — knappast tänka sig att utan olägenheter ersätta den med en ny term. Det är däremot möjligt att placera s. k. Kalixpinnmo under en större gruppbeteckning och bibehålla beteckningen Kalixpinnmo endast för den ursprungliga avlagringstypen. På så vis kunde man förhindra att denna beteckning sprides att omfatta alla liknande bildningar. Vidare skulle man få en möjlighet att då så anses nödvändigt eller önskvärt undvika beteckningen Kalixpinnmo. Frågan är nu vilken gruppbeteckning man skulle välja. För avlagringar, som genetiskt sett är att hänföra till morän, men som ur sammansättningssynpunkt närmast är eller närmar sig sorterade jordarter, kan man använda gruppbeteckningen ofullständig morän. Ur genetisk synpunkt kan man skilja på tre huvudtyper av ofullständig morän. 1. Lokalmorän av rösbergsmoränkaraktär, d. v. s. isen har brutit i fast berg men endast i ringa grad transporterat och bearbetat utgångsmaterialet. 2. Lokalmorän av vissa sedimentära bergarter. Isen krossar ned ett enhetligt utgångsmaterial till en morän med relativt hög sorteringsgrad och denna morän avlagras innan den blandas med annat bergartsmaterial. 3. Lokalmorän som bildats huvudsakligen på bekostnad av sorterade jordarter. I detta fall kan det vara svårt att avgöra om det sorterade materialet ursprungligen avsatts utanför en iskant eller om det bildats subglacialt i nära genetiskt sammanhang med moränen.

Det föreligger alltså viktiga principella skillnader mellan de tre nämnda fallen och lämpliga beteckningar för olika hithörande moräner får väljas från fall till fall beroende på sammanhanget. Det som här är aktuellt att diskutera är frågan hur man lämpligen bör benämna moräner av den tredje huvudtypen. Bland svenska kvartärgeologer är det ganska vanligt, att man använder termen sediment som synonym till sorterade jordarter. Med hänsyn till termens användning i allmän geologi och i utländsk kvartärgeologi måste det tyvärr anses olämpligt att använda termen sediment i den nämnda begränsade betydelsen. Om så ej vore fallet skulle man med ett gemensamt namn kunna kalla de ofullständiga moräner, som bildats på bekostnad av sorterade jordarter, för sedimentmoräner. I vissa sammanhang använder man termen oscillationsmorän för hithörande bildningar. Denna term säger, att avlagringen ifråga bildats vid en isoscillation, men ej att avlagringen bildats på bekostnad av sorterade jordarter. Oscillationsmoräner kan lika gärna ha bildats av t. ex. tidigare avsatta moräner. När man vill dela upp sådan ofullständig morän, som bildats på bekostnad av sorterade jordarter, synes det vara lämpligast att förfara på samma sätt som vid uppdelningen av normala moräner, d. v. s. den eller de korngrupper, som dominerar materialet, anges med adjektivbestämningar. En ofullständig morän, som huvudsakligen består av t. ex. grovmo, skulle då benämnas ofullständig grovmoig morän. Det kanske kan invändas, att enär man för normala osorterade moräner med adjektivbestämningar endast anger de dominerande korngrupperna och sedan underförstår de övriga, så kan detta skrivsätt vara vilseledande, när det gäller ofullständiga moräner. För undvikande av missförstånd skulle man i det senare fallet kunna låta den dominerande korngruppen ingå i substantivet, t. ex. ofullständig grovmomorän. Som ett exempel på en annan typ av ofullständig morän kan vissa delar av den lågbaltiska moränleran i sydvästra Skåne nämnas. Denna är delvis lik en sedimentär lera och till stor del måste den också ha bildats på bekostnad av tidigare avsatt lera (se t. ex. Möller 1959 samt där anförd äldre litteratur). På sid. 196 omtalas en annan, i ett avsnitt av en moränskärning i Stockholmstrakten, påträffad typ av ofullständig morän.

---

[1] Bl. a. är den folkliga benämningen pinnmo i större delen av landet sedan gammalt i huvudsak bunden till de packade osorterade bottenmoränerna, alltså jordarter, som så väl till fysikaliska egenskaper som till bildningssättet är helt skilda från s. k. Kalixpinnmo.

Lälinsmorän

LOKALBESKRIVNINGAR

Komplexa avlagringar med morän och i denna mer eller mindre rikligt förekommande linser av sorterat material har flerstädes påträffats på bergens och hällarnas läsidor, sett i förhållande till de sista isrörelseriktningarna. För dylika lägesbundna avlagringar användes nedan termen lälinsmorän.

Lälinsmorän är i regel löst lagrad. Inslag av ofullständigt sorterade partier i den osorterade moränmassan är vanliga i lälinsmorän. I de inom undersökningsområdet påträffade lälinsmoränerna har den egentliga osorterade moränmassan haft en något högre sorteringsgrad än den omgivande moränen, som icke ligger i läläge. Termen lälinsmorän är med avsikt vald så, att den endast skall kunna användas för sådana bildningar på bergens och hällarnas läsidor (eller andra lälägen), som har de nämnda kännetecknen, linser etc. De övre delarna av moränavlagringarna på läsidorna utgörs nämligen ofta, åtminstone inom här undersökt område, av en helt annan moräntyp; hårt packad, linsfri morän, ofta med tydlig presstruktur. Med andra ord kan man säga, att en moränavlagring på en läsida (t. ex. Crag and tail) till en viss del kan utgöras av lälinsmorän.

Termen lämorän (läsidesmorän), som kanske hade varit att föredraga före termen lälinsmorän, har tidigare använts för moränavlagringar i sin helhet på läsidor (t. ex. Munthe 1906, p. 76 och 1928, p. 88; Björsjö 1949). Även om man därvid för lämoränens inre byggnad angett vissa särdrag (Björsjö 1949), som till en del överensstämmer med lälinsmoränens, har termen främst varit bunden till avlagringen i sin helhet. Björsjö använde beteckningen lämorän för de först av Hessland (1942, 1943) beskrivna glacigena proximalavlagringarna (»hydrodynamisch angereicherte glazigene Grobsedimente»), som förekommer på läsidor i vissa av Bohusläns sprickdalar.

På fig. 1 har läget för ett antal lokaler med moränskärningar markerats. I stort sett gäller att bergens och hällarnas sydsidor varit läsidor, sett i förhållande till de sista isrörelserna (jfr sid. 191). Inom området har lälinsmorän förekommit i samtliga på läsidor påträffade större moränskärningar. I skärningarna i stötsidornas och annan i icke läläge liggande morän (med undantag för

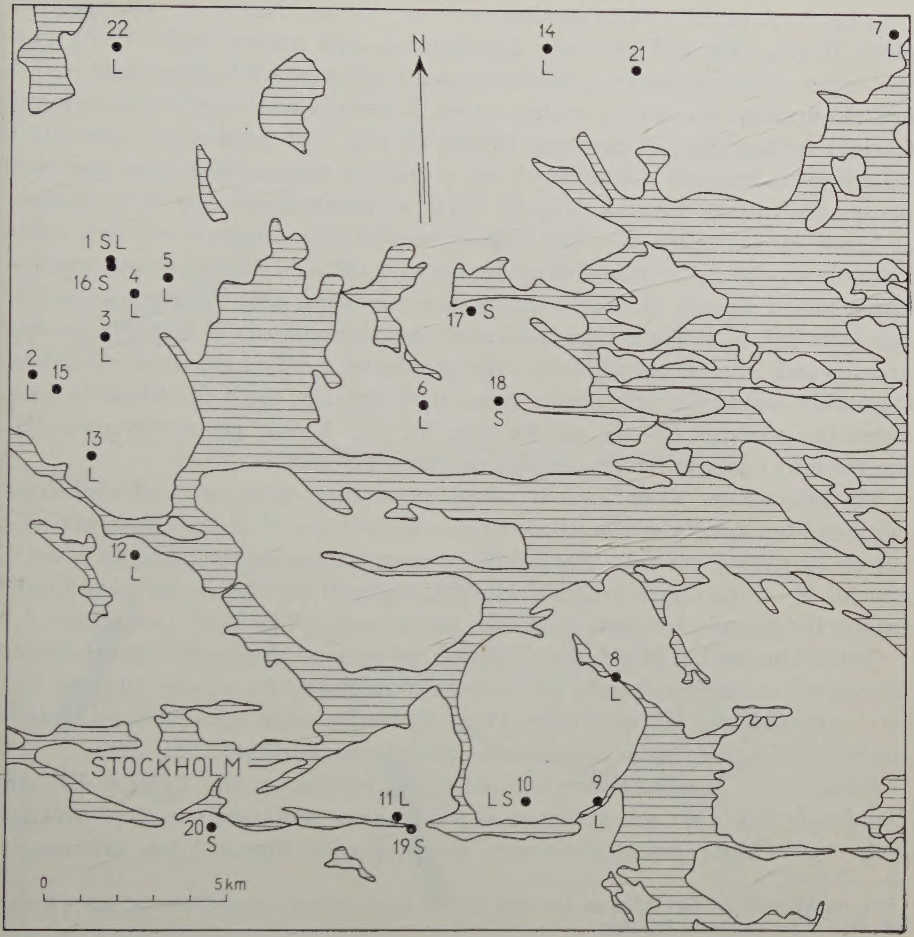


Fig. 1. Karta över numrerade lokaler med moränskärningar.

L = Morän med linser av sorterat material förekommer i läläge (lälinsmorän), sett i förhållande till de sista isrörelseriktningarna.

S = Moränen på stötsidan av en häll eller berghöjd är hårt packad bottenmorän utan linser av sorterat material.

Map of localities with sections in till deposits.

L = Till with lenses of sorted material found on the lee sides of rocky knolls.

S = The till on the stoss side is hard packed and lacks lenses of sorted material.

ändmoräner och invid isälvsstråk avsatt morän) har linsförande morän däremot icke påträffats. Bortsett från ytskiktet med svallad morän har moränen i de sistnämnda skärningarna nästan genomgående utgjorts av hårt packad, sandig-moig morän, ofta med tydlig presstruktur. De på fig. 1 markerade lokalerna med moränskärningar redovisas nedan. I samtliga fall gäller det normalblockig eller blockfattig urbergsmorän med högst 4 dm mäktigt svallat ytskikt. Ett L efter lokalnumret anger att lälinsmorän förekommer, ett S att hård, linsfri morän av bottenmoräntyp förekommer på stötsidan.

Lokal 1 (L och S). Skärning 900 m N om Roslags Näsby stn. En uppmätt profil återges i fig. 2. Figurtexten kompletteras med nedanstående. På figuren har endast de större linserna i lälinsmoränen medtagits. I lälinsmoränens egentliga moränmassa fanns även smärre linser. Linsmaterialets höga sorteringsgrad framgår av kurvorna för proverna 67 och 68 (fig. 3).[1] Sanden och grovmon i de större linserna var strömskiktad och gränserna mellan olika lager i en och samma lins var väl bevarade (fig. 4). Direkta deformationer eller skiktstörningar kunde ej iakttagas i linserna. Gränsen mellan lälinsmoränen och den överlagrande moränen var något flytande, dock ej diffus. Lälinsmoränens moränmassa har, i motsats till den ovanliggande moränen, dels låg packningsgrad, dels lägre halt av mjäla och ler. Lälinsmoränens sorteringsgrad är högre än den ovanliggande moränens. Jämföres lälinsmoränens moränmassa med stötsidans morän blir motsatsförhållandet än mera utpräglat. Det sagda illustreras av kurvorna för proverna 69—71 och 64 (fig. 3). Fig. 5 visar ett avsnitt med den mycket hårt packade, sandiga-moiga moränen på stötsidan.

Vid längdmåttet 50 m fanns ett några meter långt snitt, som gick vinkelrätt mot den i fig. 2 återgivna profilen. I det ungefär i O—V utsträckta snittet, vilket ej återgetts i profilen, framträdde presstrukturen än tydligare än i det i ungefär N—S utsträckta snittet. I vinkelställda snitt på hällens nordsida kunde samma förhållande konstateras, likaså i skärningen vid lokal 19 (se nedan).

Grusskiktet mellan längdmåtten 56 och 64 m samt det mellan längdmåtten 58 och 60 m förekommande partiet med finmoig-mjälig morän (fig. 2) har intet samband med lälinsmoränen. Dessa företeelser samt lagerföljden i vinkelsnittet vid längdmåttet 60 m behandlas därför separat på sid. 196—200.

Lokal 2 (L). Moränskärning i V—O på sydsidan av en häll 1 100 m NV om Danderyds k:a. Den genomskurna sandiga-moiga moränen var 3 m mäktig, hade normal block- och stenhalt samt var mycket löst lagrad. I hela skärningen

---

[1] För undvikande av förväxlingar används här de provnummer, som gäller i det större material, från vilket proverna hämtats.

▶

Fig. 2. Profil vid lokal 1, 900 m N om Roslags Näsby stn.

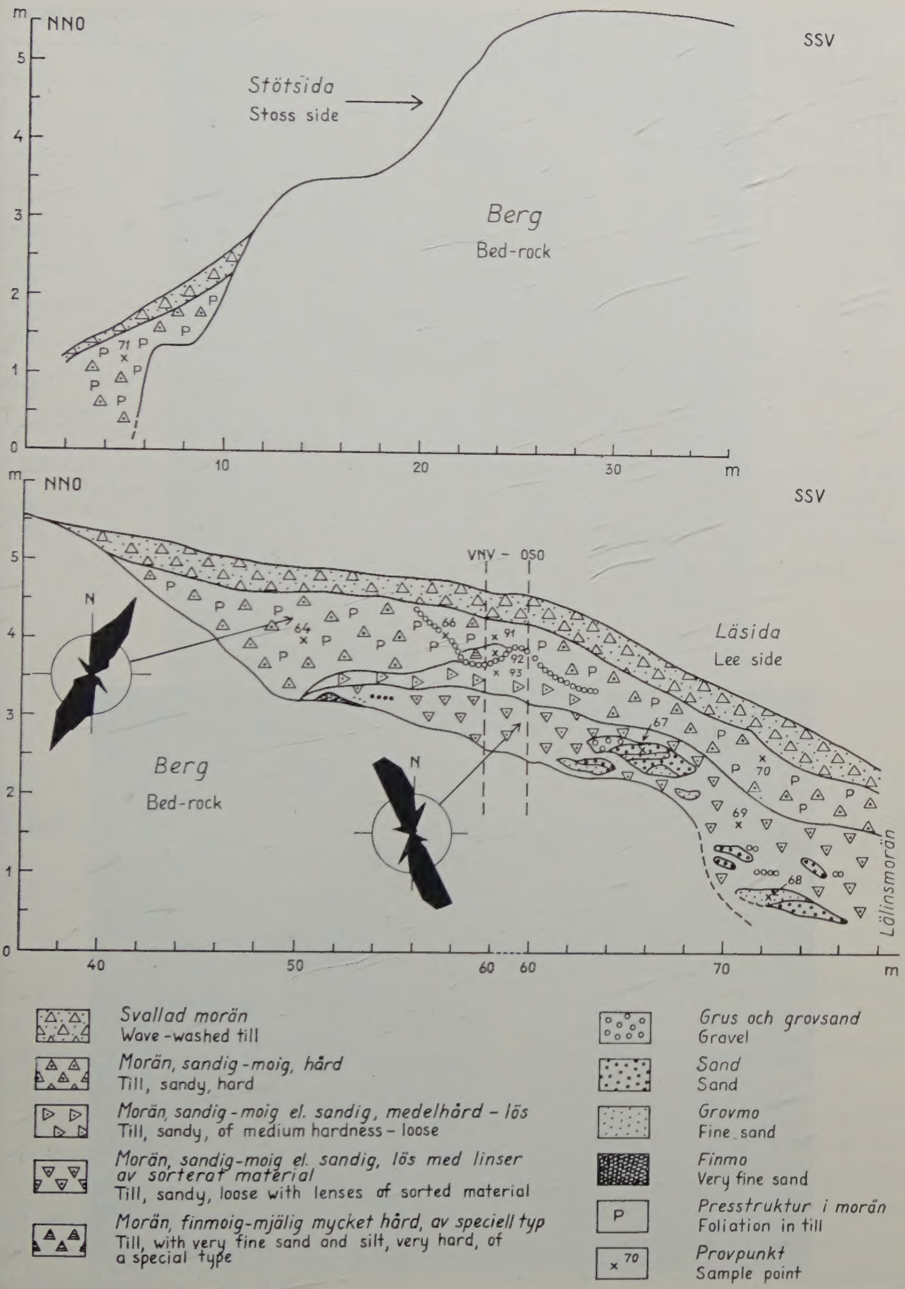
Profilen får representera det flerstädes iakttagna förhållandet med löst lagrad, av grus-, sand- och molinser uppspaltad morän på hällarnas läsida, sett i förhållande till de sista isrörelseriktningarna. Dylika komplexa avlagringar har här benämnts lälinsmorän. I profilen ovan samt i flera andra av de på fig. 1 med L markerade skärningarna utgörs de ytligare delarna av moränavlagringen på läsidan av hårt packad morän, vilken saknar linser och i stor utsträckning visar presstruktur. Detta är en typisk bottenmorän. Samma moräntyp, ehuru ännu hårdare packad, finns på stötsidan (jfr fig. 5).

Grusskiktet i lagerföljdens övre del mellan längdmåtten 56 och 64 m samt det mellan längdmåtten 58 och 60 m förekommande partiet med finmoig-mjälig morän har intet samband med lälinsmoränen och omtalas närmare i texten (sid. 196—200).

Analyser av i profilen tagna prover redovisas i fig. 3 och fig. 16.

De infällda rosdiagrammen visar blockens orientering i de avsnitt till vilka pilarna dragits. Antal block i varje bestämning = 100. Cirklarna markerar 10 %.

In the investigated area this section at locality 1 (fig. 1) may represent a common type of section in crag and tail. In the Swedish text till with lenses of sorted material on lee sides has been called »lälinsmorän». The thin stratum of gravel between 56 and 64 m and the little portion of till between 58 and 60 m do not belong to the »länslinsmorän» (compare figs 14, 15 and 16). The curves in figs 3 and 16 show the composition of the samples. The long-axis diagrams show the orientation of boulders at the two points marked with arrows. The circles mark 10 %.


m
NNO
SSV
Stötsida
Stoss side
Berg
Bed-rock
71
0
1
2
3
4
5
10
20
30
m
NNO
SSV
VNV – OSO
N
64
66
91
92
93
67
70
69
68
Läsida
Lee side
Berg
Bed-rock
Lälinsmorän
40
50
60
60
70
m
Svallad morän
Wave-washed till
Morän, sandig-moig, hård
Till, sandy, hard
Morän, sandig-moig el. sandig, medelhård – lös
Till, sandy, of medium hardness – loose
Morän, sandig-moig el. sandig, lös med linser av sorterat material
Till, sandy, loose with lenses of sorted material
Morän, finmoig-mjälig mycket hård, av speciell typ
Till, with very fine sand and silt, very hard, of a special type
Grus och grovsand
Gravel
Sand
Sand
Grovmo
Fine sand
Finmo
Very fine sand
P
Presstruktur i morän
Foliation in till
× 70
Provpunkt
Sample point

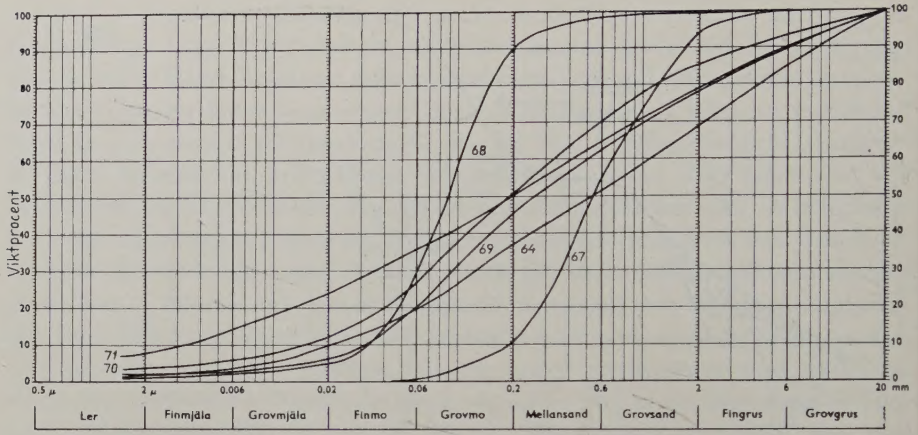


Fig. 3. Kumulativdiagram över korngruppsfördelningen i jordprover från profilen vid lokal 1 (se fig. 2). Kurvorna för proverna 67 och 68 visar linsmaterialets höga sorteringsgrad.
Lälinsmoränens egentliga moränmassa (69) har högre sorteringsgrad (lägre halt av finmaterial) än den överlagrande moränen på läsidan (64 och 70) och stödsidans morän (71).

Cumulative diagram showing the composition of samples in the section at locality 1 (fig. 2).

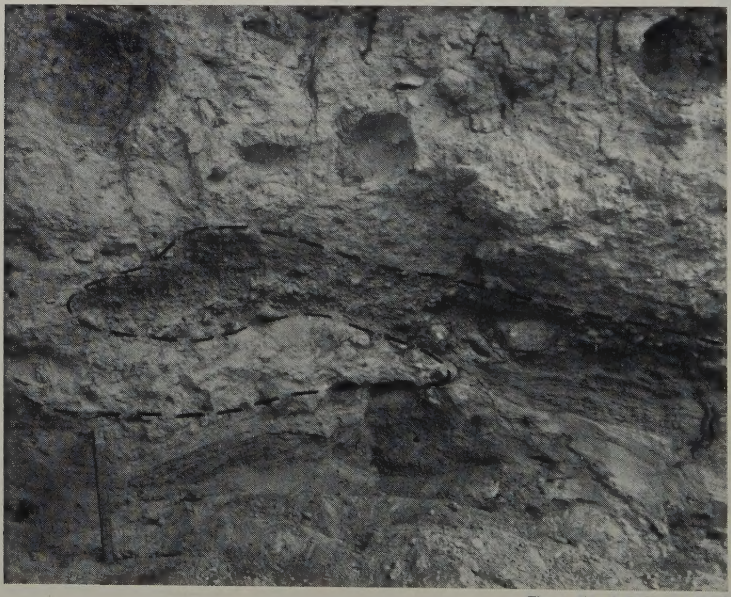


Foto H. Möller 1959.

Fig. 4. Detalj i lälinsmoränen vid lokal 1 (jfr fig. 2). Ovan den streckade linjen ligger överst hårt packad bottenmorän, därunder lälinsmoränens egentliga moränmassa. Under linjen en komplex grus-, sand- och grovmolins. Den skiktade sanden till höger ligger med en skarp gräns direkt på skiktad grovmo (den ljusa ytan i högra hörnet). Måttstocken är 24 cm lång.

Detail in the section at locality 1 (fig. 2). Above the broken line: till. Beneath the line: a lens of sorted gravel and sorted, stratified sand and very fine sand. The stick is 24 cm in length.

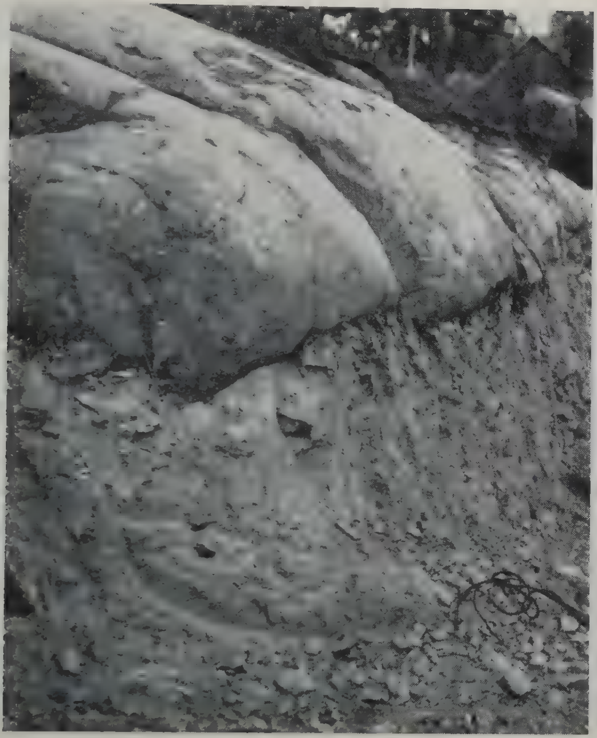


Foto H. Möller 1959.

Fig. 5. Ett i O—V utsträckt avsnitt av skärningen på stötsidan vid lokal 1 (jfr fig. 2). N är at höger på bilden. Moränen var här en mycket hårt packad bottenmorän med presstruktur (ej synlig på bilden), samt helt i avsaknad av linser. Moränen har pressats in under den mot N buktande hällytan. Kurvan för prov 71 i fig. 3 visar moränmassans sammansättning.

Very hard packed lodgement till on the stoss side at locality 1 (fig. 2). The till in all sections on stoss side in the investigated area is of this type and lacks lenses of sorted material.

fanns rikligt med mer eller mindre horisontella sand- och gruslinser, i mäktighet växlande mellan 1—4 dm. Fig. 6 visar ett avsnitt av skärningen. Prov 35 (fig. 7) taget 2 m u. y. visar moränmassans sammansättning. Moränmassan hade ställvis högre sorteringsgrad än prov 35 visar.

Lokal 3 (L). Skärning 250 m S om Enebybergs hpl. En i N—S utsträckt moränrygg på sydsidan av en stor häll (crag and tail) är genomskuren av ett ca 30 m långt snitt utsträckt i NV—SO. Under ytskiktet (ca 3 dm) med svallad morän finns i hela skärningen hårt packad, sandig-moig morän med presstruktur synlig i de övre delarna. Från 1—1.5 m under markytan och nedåt utgörs väggarna av rasmaterial. Enligt ett flertal punktobservationer, där rasmaterialet schaktades undan, synes skärningens nordvästra och centrala del utgöras av hård, sandig-moig morän ned till 3—4 m djup. I sydöstra delen av skärningen var denna moräntyp, här med presstruktur, endast 1/2—1 m mäktig. Den underlagrades av lös morän med linser av väl sorterad sand och grovmo. Bl. a. frilades en över flera meter utsträckt sådan med väl sorterad, ström-

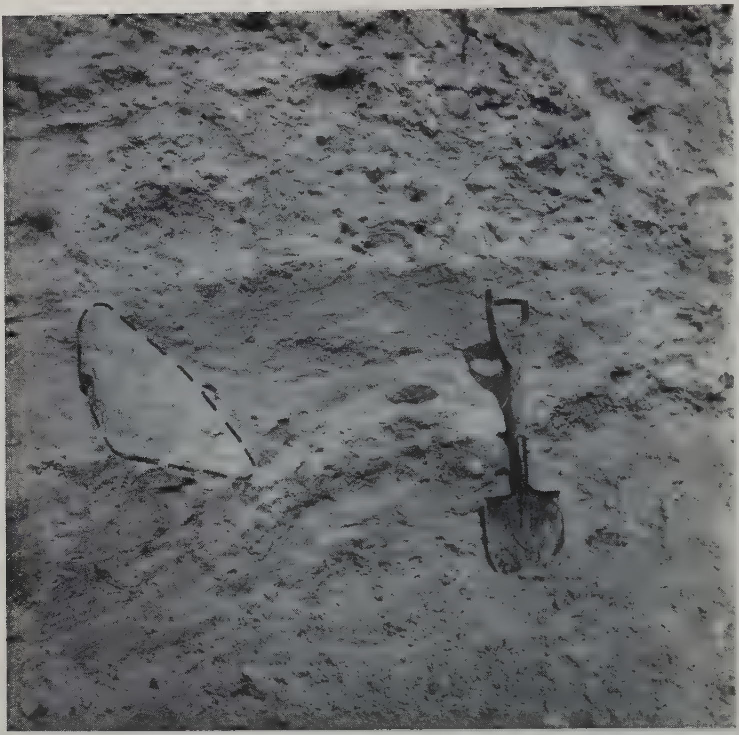


Foto H. Möller 1959.

Fig. 6. Ett i V—O utsträckt avsnitt av en skärning på sydsidan av en berghäll, 1.1 km NV om Danderyds k:a (lokal 2). Moränen är mycket löst lagrad och har rikligt inslag av sand- och gruslinser (lälinsmorän). Till vänster om spadhandtaget och spadbladet ligger två större sandlinser skilda åt av egentlig moränmassa. Den streckade linjen inringar ett block. Till höger om spadskaftets mitt ligger ett grusskikt. Kurvan för prov 35 i fig. 7 visar moränmassans sammansättning.

A part of section (locality 2, fig. 1) in a till deposit on the lee side of a knob of rock (crag and tail). The till is very loose and lenses of sand and gravel are common. Two bigger lenses of sand are situated to the left of the handle and the blade of the spade respectively. The broken line marks a boulder. A stratum of gravel is situated to the right of the handle of the spade. The curve for sample 35 (fig. 7) shows the composition of ordinary till in this section.

skiktad grovmo. Linsen (eller lagret) var upp till 70 cm mäktigt och låg direkt under den här 1/2 m mäktiga, hårda moränen med presstruktur. Berget låg mycket nära, om icke direkt under denna lins.

Lokal 4 (L). Moränskärning i en berghöjds sydsluttning 550 m Ö om Roslags Näsby stn. Under ytskiktet med svallad morän fanns 1 m mäktig hårt packad och pressad, sandig-moig morän. Denna underlagrades av 1—1.5 m mäktig, löst lagrad morän med ett flertal grus-, sand- och molinser. Grovmolinser dominerade. En 2—3 dm mäktig sådan utgjordes av väl sorterad grovmo. Denna lins låg endast någon dm ovanför bergytan och syntes ställvis ligga direkt på berget.

Lokal 5 (L). Moränskärning i en berghöjds sydsluttning 1 500 m ONO om Roslags Näsby stn. Moränen var upp till 8 m mäktig. De undre 4 m kunde ej studeras närmare p. g. a. ras. De ytligaste delarna högst upp i sluttningen var

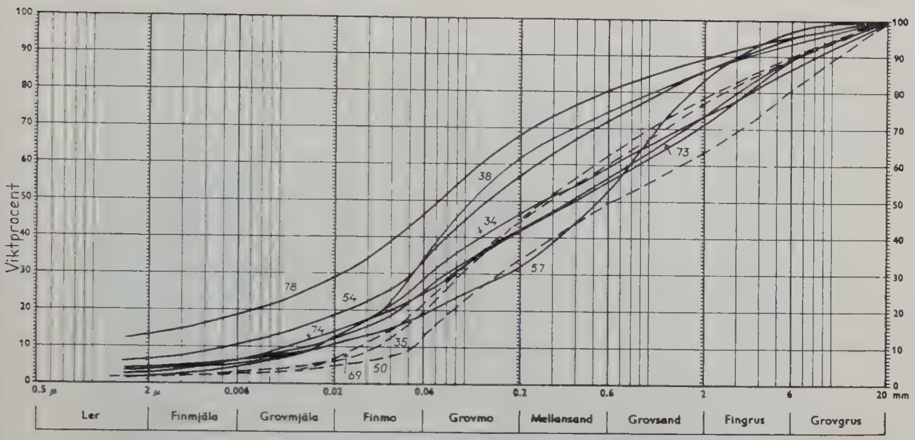


Fig. 7. Kumulativdiagram över korngruppsfördelningen i moränprover från olika lokaler Streckade kurvor representerar lälinsmoränernas egentliga moränmassa. Heldragna kurvor representerar stötsidornas och andra i icke lälägen liggande moräner. De förra har högre sorteringsgrad (lägre halt av finmo-ler).

Cumulative diagram showing the composition of samples taken at different localities. Broken curves represent the ordinary till in till deposits with lenses of sorted material on the lee sides. Unbroken curves represent till deposits on the stoss sides and other till deposits which are not situated on lee sides.

under svallskiktet hårt packade och visade presstruktur. I övrigt var moränen löst lagrad samt rik på grus-, sand- och grovmolinser.

Lokal 6 (L). Moränskärning i en berghöjds sydsluttning vid vägen 1 250 m VSV om Söderby gård på Bogesundslandet. Moränen är på det mäktigaste stället i sluttningen 4—5 m mäktig. Block- och stenhalten är normal. I de övre delarna är moränen lös och sandlinser förekommer tillsammans med partier av moränmaterial med relativt hög sorteringsgrad. Prov 50 (fig. 7) har tagits 3 m u. y. Nedåt är moränen medelhård och av normal osorterad, sandig-moig typ. Rasmaterial hindrade närmare undersökning av denna, men linser med sorterat material tycktes dock förekomma.

Lokal 7 (L). Moränskärning i en berghöjds sydsluttning vid vägen 400 m NV om Skeppsdals brygga. Under ytskiktet med svallad morän fanns 3—4 dm mäktig sandig-moig morän med presstruktur. Därunder fanns löst lagrad morän med linser av sorterat material. Rasmaterial hindrade närmare undersökning, men bl. a. kunde en utsträckt 2—3 dm mäktig lins med ren mo blottläggas.

Lokal 8 (L). Moränskärning i en berghöjds sydsluttning 500 m Ö om Boo k:a. Följande profil uppmättes:

A. 0.7 m Svallsand och svallad morän
B. 0.7 m Medelhård, sandig-moig morän med en del smärre sandlinser
C. 0.6 m Lös morän med sand- och gruslinser

Lokal 9 (L). Moränskärning i en berghöjds sydsluttning 600 m SSV om Boo gamla k:a. Under den 2—3 dm mäktiga svallade moränen fanns ca 7 dm mäktig, hårt packad, sandig-moig morän. Därunder följde en lös morän med mera sorterade partier och linser av sorterat material.

Lokal 10 (L, S). Vägskärning 1 200 m Ö om Tollare folkhögskola. I ett snitt, utsträckt i V—O, på sydsidan av en häll vid vägens norra sida uppmättes följande lager:

A. 0.3 m Svallad morän
B. 0.5 m Hårt packad, sandig-moig morän (med låg sandhalt)
Presstruktur synlig i vissa partier
C. 0.3 m Medelhård—lös, sandig-moig morän (med högre sandhalt än lager B)
D. 0.7 m Lins med sorterat material (i huvudsak mo)
I vertikal led var linsen 5 m lång. På det mäktigaste stället var den 0.8 m mäktig.
E. Berg

Lager D utgjordes huvudsakligen av grovmoig finmo. I denna förekom tunna veckade skikt med grovmo. På ett ställe fanns en rund inneslutning (ca 1 dm i diameter) av grovmo. Hela linslagret var hårt packat. Lagringsförhållandena samt packningen i lager D tyder på att detta pressats av isen. I nedre delen av lager D var materialet mera moränartat med sten och grus i den moiga sorterade grundmassan. Även högre upp i lagret förekom smärre partier med sådan sammansättning. I skärningens västra del, vilken ej låg i så utpräglat läläge kilade linsen ut snett nedåt. I östra delen gränsade linsen med en nästan lodrät gräns mot moränen (fig. 11).

På vägens södra sida fanns flerstädes genomskuren morän i en ca 100 m lång skärning (huvudsakligen berg), utsträckt i O—V. Moränen ligger här på en större berghöjds nordsluttning och befinner sig ej i läläge i förhållande till den ovan nämnda mindre hällen på vägens norra sida. Bortsett från några få dm-stora, sandiga-grusiga linser omedelbart under den osvallade moränens yta, saknades linser här i nordsluttningen. Moränen var sandig-moig (med låg sandhalt) och hårt packad. Presstruktur framträdde mycket tydligt på flera ställen, bl. a. skiffrig sådan.

Lokal 11 (L). Två moränskärningar i en berghöjds sydsluttning vid landsvägen ca 700 m VNV om Saltsjö-Duvnäs hpl.

Lokal 12 (L). Moränskärning i en berghöjds sydsluttning 600 m V om Riksmuseet. (enl. G. Lundqvist)

Lokal 13 (L). Moränskärning i en berghöjds sydsluttning 300 m NV om Mörby lasarett. (enl. J. Lundqvist)

I skärningarna vid lokalerna 11, 12 och 13 fanns löst lagrad morän med linser av sorterat material.

Lokal 14 (L). Skärning i sluttningen på sydostsidan av en berghöjd 1.5 km NNO om Åkersrunö stn. Lagerföljden i skärningen var något växlande, men inom ett väl blottat ca 30 m långt avsnitt, utsträckt såsom fig. 8 visar, fanns följande lager: Överst 1.2 m postglacial lera, som ställvis underlagrades av 0.1—0.2 m varvig glacial lera. Under leran låg 0.6 m svallsediment (i huvudsak

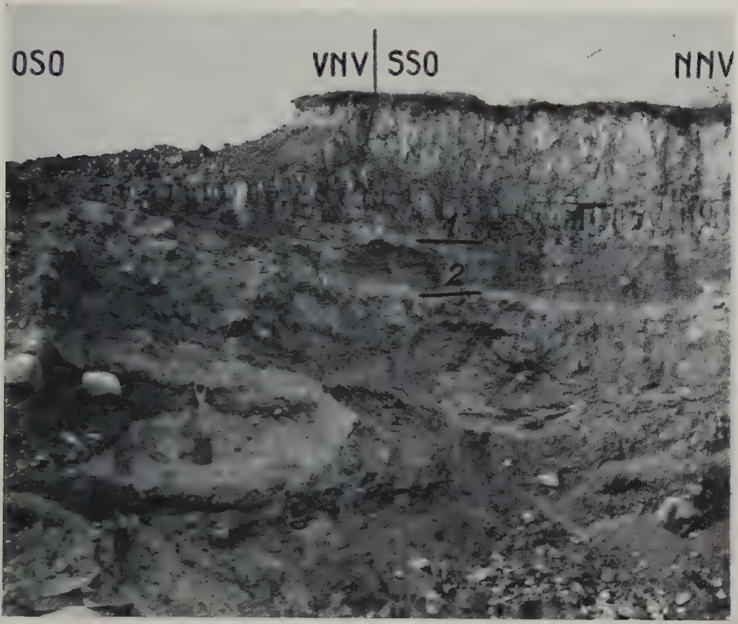


Foto H. Möller 1959.

Fig. 8. Ett avsnitt av en skärning på sydostsidan av en berghöjd, 1.5 km NNO om Åkersrunö stn (lokal 14). 1 = Postglacial lera och ställvis tunn glacial lera. 2 = Svallsand. Därunder lälinsmorän med små och stora linser av sorterat material. Vid spaden ligger en stor lins av nästan ren grovmo. Den i denna från vänster inskjutande kilen utgörs av ofullständigt sorterad, något stenig grusig sand.

A section on the lee side of a large knob of rock at locality 14 (fig. 1). 1 = Postglacial clay and partly glacial clay. 2 = Sand, wave-washed. Below 2: till with large and small lenses of sorted material. A particularly large one of almost pure fine sand is situated at the spade. This lens (light) is partly divided by a layer of incompletely sorted, stony, gravelly sand (to the right and the left of the handle).

svallsand) vilande på en uthållig ca 1 m mäktig moränbank med grovmoig-sandig morän. Denna hade ställvis hög grushalt och tunna linser av sorterat material. Under moränbanken låg i avsnittets södra del en 1 m mäktig lins av ren grovmo i vilken några enstaka stenar hittades. Ett lager med ofullständigt sorterad, något stenig grusig sand sköt in i grovmolinsen från OSO och spaltade upp denna så som fig. 8 visar. I sydöstra delen av detta ofullständigt sorterade lager fanns några mindre block. Mot N gränsade grovmolinsen mot ofullständigt sorterad, grusig stenig sand. Under den nämnda 1 m mäktiga moränbanken låg längre mot N en av steniga och grusiga skikt uppspaltad morän. Därunder följde ett 0.5 m mäktigt lager med ofullständigt sorterat, stenigt grus, vilket i sin tur vilade på morän. Denna kunde ej närmare studeras p. g. a. rasväggar, men på åtkomliga ställen var den en block- och stenfattig, sandig-moig morän med låg grushalt.

Lokal 15. Moränskärning i flack terräng 700 m N om Danderyds k:a. (prov 34, fig. 7)

Lokal 16 (S). Moränskärning i en berghöjds nordostsluttning 800 m N om Roslags Näsby stn. (prov 38, fig. 7)

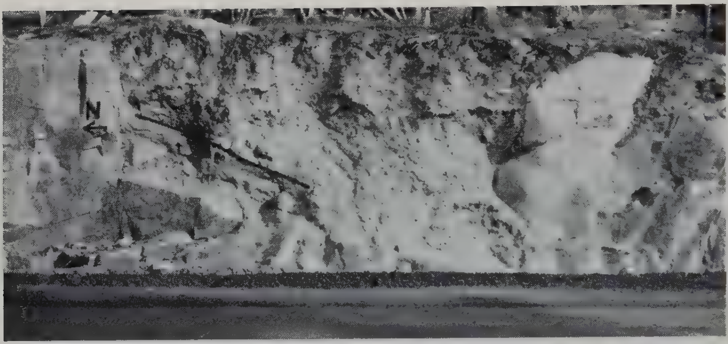


Foto H. Möller 1959.

Fig. 9. Vägskärning 800 m NNO om Täby k:a (lokal 22). Haket i berget är utfyllt med morän. Vid spaden (under den markerade gränsen) är moränen uppspaltad av sand- och grusskikt. I övrigt utfylles haket av hård, sandig-moig morän utan linser.

A section looking east at locality 22. The cavity in the bedrock is filled up with till. In the till below the marked line strata of sand and gravel occur. The remaining part of the cavity is filled up with hard packed. sandy till which lacks lenses of sorted material. The last ice-movements were in directions nearly N—S.

Lokal 17 (S). Moränskärning i en berghöjds nordsluttning 250 m SO om Ladviks skogsvårdsgård på Bogesundslandet. (prov 54, fig. 7)

Lokal 18 (S). Moränskärning i en berghöjds nordsluttning 900 m OSO om Söderby gård på Bogesundslandet. (prov 57, fig. 7)

Vid lokalerna 15—18 har moränen iakttagits till ett djup av 2—3 m och på 40—60 m längd. I samtliga fall förekom under det svallade ytskiktet medelhård-hård, sandig-moig morän utan linser, vid lokal 18 dessutom blockfattig med tydlig presstruktur. Vid lokal 15 gick skärningen ned till berg.

Lokal 19 (S). Moränskärning i en berghöjds nordsluttning vid vägen 400 m V om Saltsjö-Duvnäs hpl. Skärningen ligger på södra dalsidan av en i O—V framgående stor sprickdal. Större delen av skärningen, som skjuter in i moränsluttningen, är utsträckt i O—V. Sidoväggarna böjer av mot N. Följande lager är representativa för hela skärningen:

A. 0.4 m (ställvis endast 0.2 m) Lös, svallad morän
B. 2.5 m Mycket hårt packad, sandig-moig morän med presstruktur och normal block- och stenhalt (prov 73, fig. 7). Linser saknades
C. 6—7 m Samma moräntyp som i lager B tycks fortsätta ytterligare 6—7 m nedåt på de mäktigaste ställena. Rasmaterial hindrade emellertid en närmare undersökning av moränen i primärt läge.

Presstrukturen (fig. 10) framträdde tydligast i den i O—V utsträckta delen av skärningen. Förhållandet var detsamma vid lokal 1 (se ovan).

Lokal 20 (S). Skärning vid foten av brant nordsluttning 1 200 m OSO om Skanstull. Skärningen, som låg invid den i O—V framgående förkastningsbranten, var utsträckt ca 20 m i O—V. Lagerföljden var följande:

A. 2 m Varvig glacial lera
B. 1 m Hårt packad, sandig-moig morän utan linser (prov 74, fig. 7)

Lokal 21. Moränskärning i en berghöjds östsluttning 900 m SV om Skånsta. Moränen var genomskuren till 2 m djup dels i ett ca 20 m långt snitt i N—S, dels i ett ca 10 m långt snitt i O—V. Under ytskiktet med svallad morän (0.3 m) fanns i båda snitten hårt packad, sandig-moig morän med presstruktur, delvis även lerig moig morän (prov 78, fig. 7). Linser saknades.

Lokal 22 (L). Vägskärning 800 m NNO om Täby k:a. I ett avsnitt av en i N—S utsträckt bergskärning fanns ett med morän utfyllt hak i berget (fig. 9). I hakets norra och lägsta del (verkligt läläge) var moränen uppspaltad av sand och grusskikt (linser). I övrigt var det, bortsett från ytskiktet med svallad morän, en hård sandig-moig morän, som utfyllde haket. Principen är här densamma som i de ovan beskrivna skärningarna med lälinsmorän på bergens och hällarnas läsidor.

LÄLINSMORÄNERNAS BILDNINGSSÄTT

Med utgångspunkt från ovan framlagt material skall lälinsmoränernas bildningssätt diskuteras. En sammanfattning av föreliggande fakta kan göras på följande sätt.

1. Lälinsmorän måste vara en vanlig företeelse. Det kan icke vara tillfälligheternas spel, som gjort att linsförande morän förekommit i samtliga inom undersökningsområdet på läsidor påträffade större moränskärningar.
2. Linserna utgörs i huvudsak av väl sorterat material (grus, sand och mo), vilket måste ha sorterats och transporterats i rinnande vatten. I flera linser har materialet varit tydligt strömskiktat och gränserna mellan olika lager i en och samma lins har varit väl bevarade (jfr fig. 4). Med ett undantag (lokal 10) har deformationer eller skiktstörningar ej iakttagits i linserna.
3. I de inom undersökningsområdet påträffade lälinsmoränerna har linserna till stor del varit relativt mäktiga och uthålliga. Fig. 2 ger en uppfattning om normalstorleken, fig. 8 visar dels en extremt stor grovmolins dels en mera normal sådan.
4. Inslag med övergångsformer mellan det väl sorterade linsmaterialet och den osorterade egentliga moränmassan är icke ovanligt i lälinsmorän. Fig. 6 visar ett snitt där dylika inslag förekom i stor utsträckning.
5. De påträffade lälinsmoränerna har i sin helhet (med ett undantag, lokal 10) varit löst lagrade.
6. Lälinsmoränerna har icke befunnits överlagra någon annan moräntyp. Där berget varit blottat har lälinsmoränen legat direkt på detta. Fig. 2 illustrerar förhållandet.
7. Lälinsmoränerna har vid nio lokaler överlagrats av hårt packad linsfri morän, vilken vid sex av lokalerna visade tydlig presstruktur. Gränsen mellan lälinsmorän och överlagrande morän har i regel varit tämligen skarp.
8. I flera fall (lokalerna 1, 3, 4, 10 och 22) har större linser legat mycket nära berget eller direkt på detta. Figurerna 2, 9 och 11 illustrerar förhållandet.
9. Vid lokal 3 låg en mäktig och uthållig strömskiktad grovmolins med skarp gräns direkt under hårt packad och pressad morän.

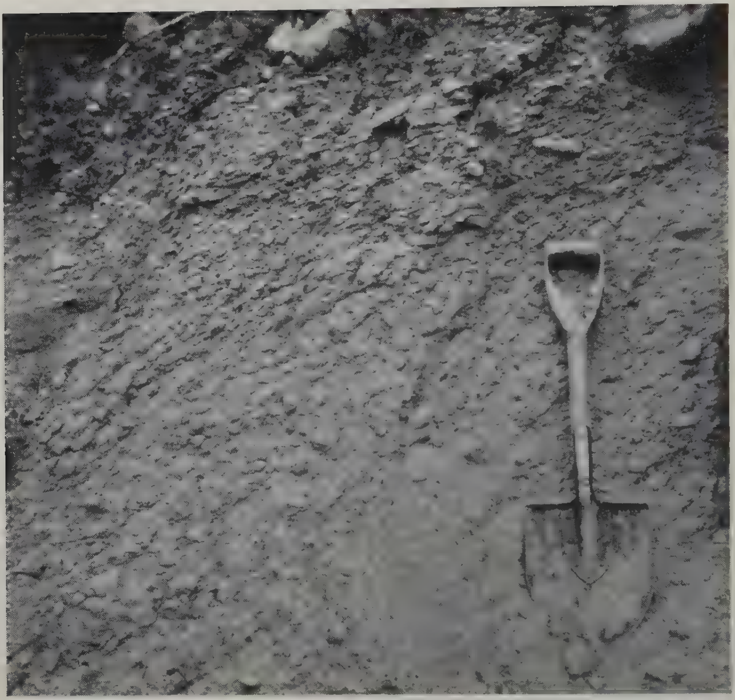


Foto H. Möller 1959.

Fig. 10. Ett i O—V utsträckt snitt i en stor moränskärning i en nordsluttning, 400 m V om Saltsjö-Duvnäs hpl. (lokal 19). Bilden visar bottenmorän med tydlig presstruktur direkt under ytskiktet med svallad morän (i övre vänstra hörnet).

Foliation in till on the stoss side at locality 14.

10. De påträffade lälinsmoränernas egentliga moränmassa har något högre sorteringsgrad (lägre halt av finmo-ler) än den hårt packade och oftast pressade morän, som vid flera lokaler (se punkt 7) befunnits överlagra lälinsmoränen (fig. 3).
11. I skärningar i stötsidornas och annan i icke läläge avlagrad morän, med undantag för ändmoräner och invid isälvstråk avsatt morän, har linsförande morän icke påträffats. Moränen i dessa skärningar har betydligt lägre sorteringsgrad (högre halt av finmo-ler) än lälinsmoränernas egentliga moränmassa (fig. 7). Stötsidornas morän har i regel varit mycket hårt packad. Vid fyra lokaler har den visat tydlig presstruktur.
12. Den ovan under punkterna 7 och 11 omtalade presstrukturen i morän har varit av något växlande utseende. Den i fig. 10 återgivna strukturtypen motsvarar närmast den typ som G. Lundqvist (1940, fig. 18) benämnt »brecciestruktur». Även de båda strukturtyperna, som G. Lundqvist (1940, fig. 15 och fig. 17) benämnt »skiffrig detaljstruktur» resp. »skivformig klumpstruktur» har påträffats i de nämnda skärningarna. Ett mycket vackert exempel på den skiffriga strukturtypen fanns vid lokal 10.

Moränavlagringar med linser av sorterat material kan tänkas bildade på flera olika sätt. De exempel på tolkningsmöjligheter, som ovan refererats på sid. 171—172, kan belysa detta. Även när det gäller att förklara bildningssättet för de lägesbundna lälinsmoränerna, finns det plats för allehanda spekulationer. Lälinsmorän kan säkerligen också ha bildats på mer än ett sätt. Med hänvisning till ovanstående fakta skall några olika möjligheter diskuteras.

Den hårt packade morän (ofta med tydlig presstruktur), som vid flera lokaler överlagrar lälinsmorän är en verklig bottenmorän. I överensstämmelse med den låga sorteringsgraden och halten av finkorniga fraktioner (finmoler) måste denna morän i förhållandevis stor utsträckning ha transporterats och bearbetats i isen (jfr t. ex. G. Lundqvist 1940; Hörner 1946). När isen avsmälte från området var den levande, vilket bl. a. visas av de bekanta årsändmoränerna (G. De Geer 1932; 1940). Avsmältningen torde till stor del ha skett genom kalvning (G. De Geer 1932). Bl. a. av denna orsak finner man sällan någon ytmorän inom området. I allmänhet anses ju moränavsättningen ske i en zon, som sträcker sig några kilometer in från isranden. Bottenmoränen måste bl. a. av nämnda skäl till stor del ha avlagrats och utgjort isens underlag innan isens randzon drog sig tillbaka. Lälinsmorän, som överlagras av dylik bottenmorän, måste alltså ha funnits på plats ännu tidigare. När kan sådan lälinsmorän ha avlagrats? Följande tre ytterligheter är tänkbara. 1. Det sorterade materialet, som nu förekommer i form av linser eller kanske t. o. m. lälinsmorän fanns på plats innan isen, som avlagrat bottenmoränen, ryckte fram över området. 2. Lälinsmorän avlagrades marginalt när isen, som avlagrat bottenmoränen, ryckte fram över området och blev sedan p. g. a. läget helt eller delvis bevarad mot isens senare erosion. 3. I lälägen har döda eller nästan döda ispartier avskilts från den högre upp levande isen. Vid isavsmältningen, eller t. o. m. långt efter den levande isens avsmältning från området, har dylik dödis smält och avlagrat lälinsmorän.

Det i punkt 3 skisserade förhållandet är icke troligt när det gäller mindre förekomster av lälinsmorän. Visserligen påminner lälinsmorän till en del om sådan dödismorän, som vi känner från områden med dödisavsmältning (se t. ex. Mannerfelt 1945). Men i de begränsade dödispartier, som det skulle ha gällt i de aktuella lälägena, kan det varken ha funnits transportsträckor eller vattenmängder, som står i relation till linsernas storlek och materialets höga sorteringsgrad. Förekomster av lälinsmorän, som icke täcks av bottenmorän, kan däremot tänkas avlagrade av vid avsmältningen avsnörda dödispartier. Lälinsmorän blir då en form av dödismorän. Mycket stora förekomster av lälinsmorän kan också vara en form av dödismorän, även om de helt eller delvis täcks av bottenmorän. G. Lundqvist (1940) har framhållit, att det i vissa lägen (t. ex. i lälägen) måste ha funnits dödispartier under eller inuti den levande isen. Dylik genom terrängformerna och enligt G. Lundqvist (1940) även genom hög moränhalt uppkommen dödis tillhör Ahlmanns (1938) dödisgrupp nr 2. G. Lundqvist (1940) menade, att den löst lagrade, relativt grovkorniga moräntypen av ytmoränkaraktär, som i Bergslagen ligger i dalstråken (lälägen) åtminstone till en del härrör från dylik »intraglacial dödis». Då denna moräntyp icke överlagras av bottenmorän (jfr op. cit., fig. 19 och 20) kan man emellertid icke med säkerhet avgöra om den förra härrör från »intraglacial dödis» eller en dödis, som avskilts från den levande isen när ytavsmältningen frilade höjderna. Det kan ju också vara den levande isens ytmorän.

Åtskilliga förhållanden talar för att lälinsmoräner, i den typ av lagerföljder, som representeras av fig. 2, avlagrats marginalt vid en isframstöt över området. Då bottenmoränen, som ovan sagts, till stor del måste ha avlagrats innan isens randzon drog sig tillbaka från området, kan lälinsmoränen icke ha avlagrats marginalt vid avsmältningen, så som von Post (1929) antog att vissa linsförande moränlagerföljder i västra Sverige bildats (se sid. 171). J. Lundqvist (1958, p. 61) framhöll som ett stöd för von Posts (1929) åsikt, att linsförande morän ofta påträffas i läläge (»på sydänden av en höjd») — ett läge som bör ha varit »särskilt gynnsamt för uppkomsten av glapprum mellan isen och dess underlag». När det gäller lälinsmorän, som icke täcks av bottenmorän, kan naturligtvis von Posts åsikt vara riktig. von Post förutsatte, att isen slutade med en bräcka i vatten, i vilket kantpartierna lyfts. Men hålrum mellan isen och dess underlag kan ha förekommit i lälägen även långt inne under isen (se t. ex. Carol 1947, pp. 57—59). Direkta observationer av dylika hålrum föreligger från recenta glaciärer i Alperna även långt innanför isranden. Dessa hålrum öppnas och slutes i sammanhang med plasticitetsändringarna (tryck och temperatur) i isen. Hålrummen kan också i viss utsträckning förskjutas med isen innan de åter tillsluts (Klebelsberg 1948, pp. 141 f.). Även om dessa förhållanden icke direkt kan överföras på inlandsisar är de av intresse, om man tänker sig lälinsmorän bildad marginalt vid isens framryckning.

Det sorterade materialet i linserna kan ligga i primärt eller sekundärt läge, d. v. s. ha avsatts inne i isen eller framför denna och sedan upptagits av framryckande is (jfr t. ex. G. Lundqvist 1951 och 1958, se sid. 172). I den utländska litteraturen synes den vanligaste uppfattningen vara, att linserna i allmänhet bildats inne i isen (Holmes 1949, p. 1433; Charlesworth 1957, p. 379). De ovan under punkterna 2—5 och 10 (sid. 185) anförda förhållandena talar direkt för att de aktuella linserna ligger i primärt läge. Enligt Holmes (l.c.) kan man knappast förklara hur dylika linser skulle ha transporterats intakta i isen. Under en transport i ismassan skulle isen i linserna vara i temperaturjämvikt med omgivande is och därför lika plastisk som denna. Eventuella deformationer i linserna förklaras enligt Holmes (l.c.) med samtida isrörelser, d. v. s. materialet har avsatts i en levande is (J. Lundqvist 1958, p. 59). Om linserna vid t. ex. lokal 1 ligger i primärt läge, torde materialet enligt ovanstående ha avsatts i marginala smältvattenskanaler i en framryckande is och inbäddats i av denna avlagrad morän. I lälägen blev sedan dylika marginala avlagringar bevarade mot den efterföljande isens erosion. Lälinsmoränen blev en del av isens underlag och så småningom avlastades den packade, finkornigare bottenmoränen. Skillnaden i sorteringsgrad mellan bottenmoränen och lälinsmoränens moränmassa torde i huvudsak bero på, att den förstnämnda har transporterats längre i isen varvid materialet nedkrossats mera (jfr sid. 187). I avsikt att få fram någon skillnad mellan bergartsmaterialet i lälinsmoränen och den överlagrande bottenmoränen utfördes några blockräkningar vid lokal 1. Dessa gav emellertid intet svar på den aktuella frågan. Berggrunden inom området och norr därom är tyvärr av sådan natur, att man i det aktuella blockmaterialet icke med säkerhet kan hålla isär de dominerande bergartstyperna.[1] Den nämnda skillnaden i sorteringsgrad kan också tänkas bero på, att finmaterial tvättats ur moränmassan vid dess avsättning (Hörner 1944, p. 712 samt 1946, pp. 424 ff.). I vilken utsträckning sådan urtvättning kan ha medverkat är svårt att säga, men de tunna (någon cm) mjäla- eller finmoskikt, som ibland påträffas mellan bergytan och moränen, kan tänkas vara bildade på detta sätt. Sådana skikt förekommer såväl under H. K. (Hörner 1944, p. 710) som över H. K. (Ljungner 1945, p. 229). Förekomsten av finmo direkt på berget vid längdmåttet 52 m i profilen vid lokal 1 (fig. 2) var så mäktig (ca 2 dm), att finmon endast med tvekan kan antagas bildad genom urtvättning vid moränmassans avsättning. Finmon kan eventuellt i stället härröra från sedimentlager, som avsatts utanför isranden och sedan överskridits av isen (se sid. 198). Mellan längdmåtten 52 och 56 m fanns dock tunna finmoskikt direkt på berget. Dessa har ej kunnat markeras på fig. 2. men de stod till synes i direkt samband med den markerade finmoförekomsten.

Det på sid. 185 under punkt 8 nämnda förhållandet med större linser nära eller direkt på berget bör uppmärksammas. Dessa linser består utom vid lokal 10, som är ett specialfall (se sid. 191), av väl sorterad grovmo och sand. Så förhållandevis grovt material kan icke ha bildats genom urtvättning i moränmassan vid dess avsättning. Väl sorterad grovmo och sand, samt även grus, där sådant förekommer, måste ha avsatts av smältvattenströmmar. Då dylikt sorterat material nu återfinns i lälägen mycket nära eller direkt på berget, och antages härstamma från marginala smältvattenströmmar vid isens framryckning, så kan sedimentationen ha skett dels inne under isen dels utanför iskanten. Det sistnämnda kan antagas ha dominerat, ty eljest borde det sorterade materialet i större utsträckning ha underlagrats av morän. Smältvattenströmmar inne under isen, i gränszonen mellan denna och berget, kan dock icke uteslutas, jfr ovan sid. 188 samt även Ljungners (1930) tolkning av s. k. skärformiga tråg (Sichelwannen). Enligt Ljungner och senare Johnsson (1956, p. 39 och pp. 94 ff.) skulle de av Westergård (1934) beskrivna stromatolitkalkbildningarna, som förekommer sporadiskt på glaciärslipade hällytor utmed Bohusläns och Sydnorges kust, ge ett direkt vittnesbörd om, att bergartsmjöl transporterats av subglaciala vattenströmmar (trycksmältvatten mellan isen och hällytan). Oavsett om smältvattenströmmarna avsatt materialet utanför iskanten eller inne under isen, torde detta delvis eller helt ha eroderats bort av isen på ett senare stadium. I. och J. Terasmäe (1951) samt Järnefors (1958) har i några skärningar i Uppsalatrakten iakttagit, att sorterad mo mellan morän och bergyta legat bunden till fördjupningar och svackor i denna. Den skarpa kontakten mellan grovmolinsen och bottenmoränen vid lokal 3 (sid. 179) torde vara en erosionskontakt.

---

[1] Blockräkningarna gjordes av berggrundsgeologen G. Stålhös, som har ingående kännedom om traktens berggrund.

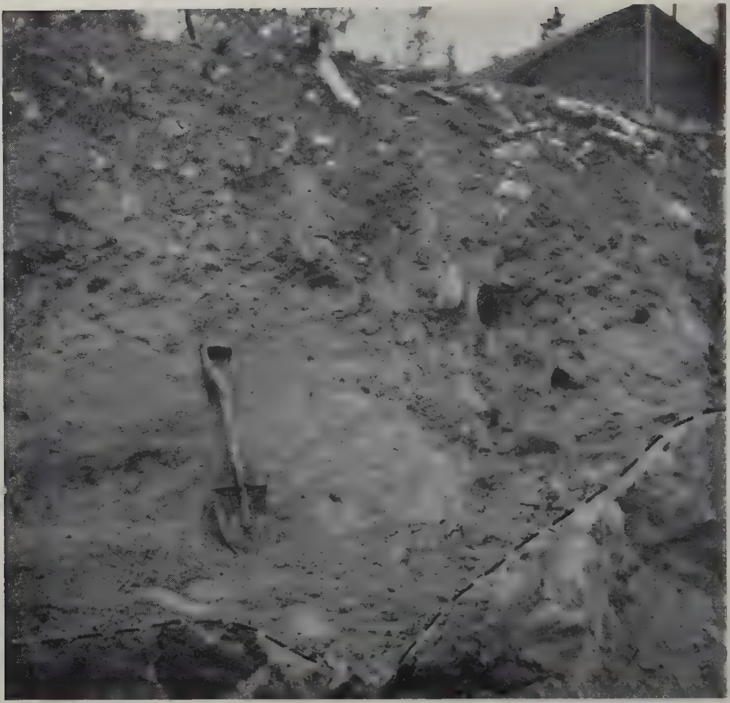


Foto H. Möller 1959.

Fig. 11. Ett i V—O utsträckt avsnitt av en skärning på sydsidan av en liten berghäll 1.2 km Ö om Tollare folkhögskola (lokal 10). Ytskiktet är svallad morän, därunder följer hårt packad, sandig-moig morän, som nedåt övergår i medelhård-lös, sandig-moig morän med högre sandhalt. Denna överlagrar en stor lins (vid spaden) av hårt packad, grovmoig finmo med tunna veckade grovmoskikt. Den streckade linjen markerar bergytan.

A section looking north on the lee side of a little knob of rock at locality 10. The last ice-movements were almost southwards. Hard packed lodgement till above passes downwards into till of medium hardness-loose covering a hard packed lens of very fine sand with contorted thin strata of fine sand. The broken line marks the bedtrock.

Som bakgrund till den fortsatta diskussionen bör man komma ihåg, att när den sista isen ryckte fram över området, torde detta till stor del ha varit täckt av tidigare bildade kvartära avlagringar (jfr punkt 1, sid. 187). Teoretiskt kan avlagringar från interglacialer, äldre istider samt tidigare faser av Würmistiden med mellanliggande interstadialer eller lokala kortvariga, isfria skeden ifrågakomma.

Vid lokal 1 var bergytan under lälinsmoränen isslipad, dock ej med räfflor. Om denna slipning gjorts av den is, som avlagrat lälinsmoränen, skulle denna icke kunna ha avlagrats marginalt vid isens framryckning. Men slipningen kan ha skett tidigare och bevisar därför ingenting om lälinsmoränens ålder. I detta sammanhang kan det vara av intresse att ställa frågan: Hur gamla slipspår kan finnas bevarade t. ex. i Stockholmstrakten? Hällytor, som slipats under Riss-istiden, får väl anses vara helt förstörda genom vittring och senare iserosion. Alldeles säker kan man dock icke vara. Det finns ingenting som hindrar, att slipade hällytor, som genom sitt läge varit skyddade mot ny iserosion och som dessutom ständigt varit vatten- eller jordtäckta, kan härröra från äldre istider. För att återgå till faktiska förhållanden så visar åtskilliga räffellokaler inom Stockholmsområdet från varandra helt skilda räffelsystem (fasettslipningar och korsande system). Det äldsta räffelsystemet, som påträffats vid kartbladsarbetet inom området, visar en isrörelse från VNV. Därnäst följer utan påvisbar övergång en isrörelse från NV. Riktningen är densamma som hos den av Frödin (1956) utskilda mesoskandiska sydostströmmen, jfr även Strömbergs (1956) undersökningar i skärgården utanför Norrtälje. Enligt Frödins (1956) undersökningar i Uppland skulle isen från den mesoskandiska riktningen (NV—SO) i stort gjort en kontinuerlig högervridning till ungefär N—S. Så kan emellertid icke ha varit fallet inom det område, som omfattas av fig. 1 (kartbladet Stockholm NO). Där finner man överallt distinkta fasettslipningar, som visar, att isrörelsen från NV är skild från en isrörelse, som satte in från ca N 30° V. Räffelsystemet från ca N 30° V i Stockholmstrakten är omtalat av De Geer (1932). Denna isrörelse har däremot, av allt att döma, genom en kontinuerlig högervridning övergått till allt mera nordliga rörelser och slutligen även till rörelser från NNO. Räffelsystem indicerande ostligare rörelser än N 20° O har under kartarbetet icke påträffats på mer än en säker lokal (N 40° O). Läget för denna är sådant, att räffelsystemet icke kan sättas i samband med någon vridning in mot ett isälvsstråk (G. Lundqvist 1955).

Med hänsyn till räfflornas vittnesbörd om isrörelsernas förlopp gjordes två blockorienteringsbestämningar (100 block vardera) vid lokal 1 (se fig. 2). Den ena gjordes i lälinsmoränens moränmassa vid längdmåttet 60 m i profilen (fig. 2), den andra i den täckande bottenmoränens övre del vid längdmåttet 50 m. Då båda blockorienteringsbestämningarna gjordes på så sätt, att ca hälften av »blocken» (stenarna) i varje bestämning mättes i en vägg och den andra hälften i en mot denna vinkelställd vägg (90°), eliminerades risken för att stenar, som är orienterade parallellt med en snittvägg, blir underrepresenterade. Resultatet av blockorienteringsbestämningarna är intressant ur mer än en synpunkt. Lälinsmoränens moränmassa och den täckande bottenmoränen har avsatts under vitt skilda isrörelser (ca N 25° V resp. ca N 30° O). Den förstnämnda bör enligt vad ovan sagts om räfflornas vittnesbörd avsatts under en relativt tidig isrörelse, bottenmoränen däremot under en betydligt yngre isrörelse. Blockorienteringsbestämningen visar, att bottenmoränens övre del (närmast under skiktet med svallad morän) avsatts under en isrörelse, som endast sporadiskt återspeglas av räfflorna. Isen torde alltså vid denna tidpunkt i huvudsak ha upphört att erodera i Stockholmsområdet.

Lälinsmoränen vid lokal 10 avviker i vissa avseenden från övriga förekomster. Linsmaterialet är särskilt finkornigt (i huvudsak grovmoig finmo). Det är hårt packat och har en slirig struktur med tunna veckade grovmoskikt. Packningen och veckningen måste ha uppkommit genom istryck (jfr sid. 182 och fig. 11). Det relativt mäktiga och finkorniga materialet torde härstamma från en skiktad avlagring, som avsatts utanför isranden och sedan överskridits av isen, varvid denna pressat materialet och stört skiktningen. Även de små partier med osorterat moränartat material, som förekom i denna lins, talar för det antagna bildningssättet. Materialet vid lokal 10 har ursprungligen varit varvigt med tunna grovmoskikt (nu veckade) i grovmoig finmo. Detta visar, att sedimentationen skett relativt nära isranden. Möjligen härrör också den vid lokal 1 direkt på berget liggande finmon från sedimentlager, som avsatts utanför isranden (se ovan sid. 189). Den vid lokal 1 påträffade finmoiga-mjäliga moränen visar, att finkorniga sediment överskridits av en oscillerande is (se nedan sid. 196).

Som ovan sagts (sid. 187) kan bl. a. sådan lälinsmorän, som icke täcks av bottenmorän, ha bildats marginalt vid isavsmältningen. Denna tolkning måste anses gälla särskilt för sådana lagerföljdstyper, som fanns i skärningen vid lokal 14 (se sid. 182 och fig. 8). Den 1 m mäktiga moränbank, som här överlagrade den stora grovmolinsen var icke av bottenmoräntyp utan grovkornigare och lösare lagrad. Dessutom förekom tunna linser av sorterat material i den nämnda moränbanken. Den av von Post (1929) lämnade tolkningen för hithörande bildningar torde här vara tillämplig (jfr sid. 171). En lagerföljdstyp av något annorlunda slag har beskrivits av G. Lundqvist (1953 pp. 53 f.). Det gäller en skärning vid Laggarbo på geologiska kartbladet Säter. Skärningen låg i en sydsluttning (läsluttning) och Lundqvist uppger, att likartade lagerföljder iakttagits i sydsluttningar på ett fåtal ställen i Uppland och Västmanland. Lundqvist beskriver skärningen vid Laggarbo på följande sätt: »Överst ligger ca 1 1/2 m pressad morän, vilken dock förlorar sin moränkaraktär, ju längre man kommer i distal riktning. Under moränen följer grus (isälvsgrus?), vilket dock utgör ytlager, där moränen saknas. Gruset blir uppåt allt sandigare. Mitt i gruslagret synes ett tunt (ett par cm) mjälskikt.» Enligt fig. 22 i det citerade arbetet var det på en sträcka av ca 6 m i sluttningens övre del som morän överlagrade grus- och sandlager. Längre ned i sluttningen gick dessa lager upp i ytan. De var minst 4—5 m mäktiga. Längst i norr underlagrades de av morän. Denna har dock (enligt den citerade fig. 22) ej direkt iakttagits på mer än en ca 1 m lång sträcka som ett mot N stigande lager (största mäktighet ca 1 m). Enligt G. Lundqvist är det troligast, att det sorterade materialet i skärningen vid Laggarbo utgör en »embryonal bildning av en ås». En annan tänkbar förklaring skulle enligt G. Lundqvist vara, att det är en svallningsprodukt, som avlagrats mellan en isrest i sänkan (St. Ulvsjön) och sluttningen i norr. En sådan tolkning förutsätter bl. a., att isen, sedan grus- och sandlagren avlagrats, åter stött fram över lokalen, varvid den pressade moränen avsatts. Även om man utgår från att grus- och sandlagren är glaciala smältvattensavlagringar, så kan bildningstiden icke fixeras. Troligast är att lagren avsatts vid den sista isens avsmältning från området, men det kan också vara äldre bildningar, som p. g. a. läläget blivit bevarade vid senare isframstötar.

Olika slag av linsförande morän

De hittills behandlade avlagringarna med linser av sorterat material i morän har främst genom det för dem alla gemensamma läläget kunnat sammanföras under beteckningen lälinsmorän. Men likartade avlagringar kan ju förekomma praktiskt taget var som helst, även om så ej kunnat påvisas inom här undersökt område. Strängt taget torde man få sammanfatta förhållandena på följande sätt: Linsförande morän kan bildas var som helst. Speciellt vanlig är sådan morän i områden med dödisavsmältning, dödismorän (se t. ex. Mannerfelt 1945). I andra områden synes utpräglade linsförande moräner vara mycket vanliga i lälägen, sett i förhållande till de sista isrörelseriktningarna. Detta behöver icke innebära, att dylika avlagringar också främst bildats i lälägen. Så kan t. ex. de förekomster, som nu täcks av bottenmorän, endast utgöra erosionsrester av avlagringar med en ursprungligen betydligt större utbredning.

De linser man oftast finner i moränavlagringar överhuvudtaget är betydligt mindre än flertalet av linserna i de ovan beskrivna lälinsmoränerna (jfr G. Lundqvist 1940, fig. 12). De förstnämnda kan man rubricera som normalfallet. Hur dessa bildats är omdiskuterat. Flera geologer anser, att linser av denna typ i allmänhet utgör rester av i fruset tillstånd upptagna sediment, som tidigare avsatts i isfritt område. I den utländska litteraturen tycks dock den vanligaste uppfattningen vara, att sådana linser i allmänhet avsatts vid isavsmältningen av temporära lokala smältvattenströmmar inne i isens randpartier (jfr t. ex. Holmes 1949, p. 1433; Charlesworth 1957, p. 379). Dylika sand- och gruslinser tycks vara särskilt vanliga i grovkorniga, luckra ytmoräner. Dessa är inom vissa områden (t. ex. i Bergslagen) i stort sett bundna till dalbottnarna och sluttningarna (G. Lundqvist 1957, p. 323). Den inom samma områden på höjderna avsatta finkornigare, packade bottenmoränen tycks däremot sällan innehålla dylika linser.

J. Lundqvist (1958) har, som en särskild typ av linsförande morän, utskilt de rikligt linsförande moräner, som anträffas i anslutning till supramarina isälvsavlagringar i norra Värmlands dalgångar (jfr sid. 172). Lagerföljder av denna typ visar, att isen i närheten av isälvsstråken varit genomsatt av större och mindre smältvattenströmmar. Dessa har säkerligen utgjort biflöden till den större isälven. Ett exempel på hithörande lagerföljder har påträffats även i Stockholmstrakten, alltså i submarin bildningsmiljö. Skärningen ligger 2 km NV om Vallentuna k:a (ca 1/2 mil N om nordvästra hörnet av det område, som kartbilden i fig. 1 omfattar). Vid en översiktsresa hösten 1959 gjorde professor G. Lundqvist mig uppmärksam på denna skärnings existens, varefter den profil, som återges i fig. 12, uppmättes. Detta snitt går utmed västsidan av en liten höjd, som ingår i östra dalsidan av en i NNV—SSO utsträckt flack dalgång. På geologiska kartbladet Rydboholm (Erdmann 1871) är en liten åskulle markerad vid platsen för skärningen. Berget, som blottats i skärningens norra del, går i dagen på en ca 25 m bred och ca 100 m i V—O utsträckt yta omedelbart N om skärningen. Några tecken på att denna höjd skulle vara en åskulle finns icke. Det är med andra ord en moräntäckt liten berghöjd. Schaktningarna i västsluttningen (omedelbart V om den återgivna profilen) har däremot gått ned i en smal sänka, som är utsträckt ungefär parallellt med profilen och som i Ö begränsas av det ovan nämnda berget och i V av en i N—S utsträckt berghäll. Sänkan är ca 20 m bred i N och mer än 50 m bred i S (bergets läge i den östliga höjden är här obekant). Schaktet, som gått ned i den

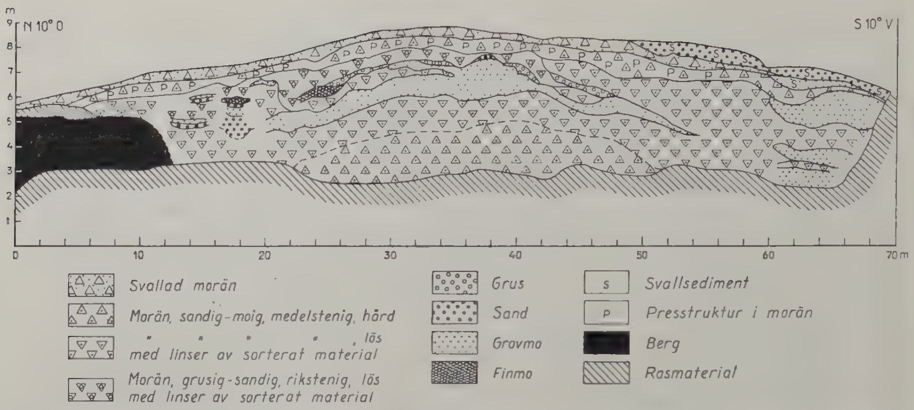

m
9
8
7
6
5
4
3
2
1
N 10° O
S 10° V
S
P
0
10
20
30
40
50
60
70 m
Svallad morän
Morän, sandig-moig, medelstenig, hård
" " " " , lös med linser av sorterat material
Morän, grusig-sandig, rikstenig, lös med linser av sorterat material
Grus
Sand
Grovmo
Finmo
S Svallsediment
P Presstruktur i morän
Berg
Rasmaterial

Fig. 12. Profil från en skärning 2 km NV om Vallentuna k:a. De rikligt förekommande stora linserna eller lagren med sorterat material, som spaltar upp en del av moränen i lagerföljden, har bildats i anslutning till en liten isälv, som runnit fram utmed en dalsida.

A section in the vicinity of Vallentuna, about 20 km N of Stockholm. The lenses or layers of sorted material, which are situated in a part of the till, have been formed in conjunction with a little esker along the lateral slope of a glen. — Morän, grusig-sandig etc. = till, gravelly-sandy, with high stone frequency, loose with lenses of sorted material; svallsediment = wave-washed deposit; berg = bed-rock; rasmaterial = material fallen down.

For explanation of the other symbols, see fig. 2.

nämnda sänkan mellan hällarna, begränsas i N av en mellan de båda hällarna ungefär i V—O utsträckt vägg. I detta snitt fanns 2—3 m mäktiga skiktade grus- och sandlager, delvis överlagrade av glacial lera. Professor Lundqvist har meddelat, att innan schaktningarna drivit den östra väggen (fig. 12) till dess nuvarande läge, visade de dåvarande skärningarna lagerföljder med mäktigare och även grövre lager av sorterat material inlagrat i morän, ungefär på samma sätt som i den uppmätta profilen. På det geologiska kartbladet (op. cit.) finns en liten åskulle markerad invid den nämnda dalgångens östra sida ca 700 m NNV om lokalen. Denna kulle är nu till största delen bortgrävd, men något tvivel om att det varit en äkta åskulle finns icke. I dalgångens östra sluttning ca 500 m N om lokalen finns ett sandtag med 4—5 m mäktig glacifluvial sand med grusskikt. De båda sistnämnda observationerna visar tillsammans med förhållandena vid den uppmätta profilen, att ett mindre isälvsstråk gått fram utmed dalsidan. Detta läge är icke ovanligt när det gäller mindre glacifluviala stråk. Motsvarande förhållanden gäller för några andra små isälvsstråk i Stockholmstrakten. Förklaringen torde vara, att isen legat an mot dalgångarnas botten, medan smältvattnet sökt sig fram utmed dalsidan. Denna tolkning har t. ex. tillämpats i Bohuslän (Hessland 1943, p. 22). De glacifluviala avlagringarna vid den uppmätta profilen och N därom har med största sannolikhet bildats när isen för sista gången drog sig bort från området. Den täckande pressade moränen av för trakten normal bottenmoräntyp visar därför, att det sorterade materialet åtminstone delvis avsatts subglacialt. Några direkta skiktstörningar eller deformationer, som skulle kunna visa, att det sorterade materialet avsatts i en levande is eller möjligen överskridits av en oscillerande is,

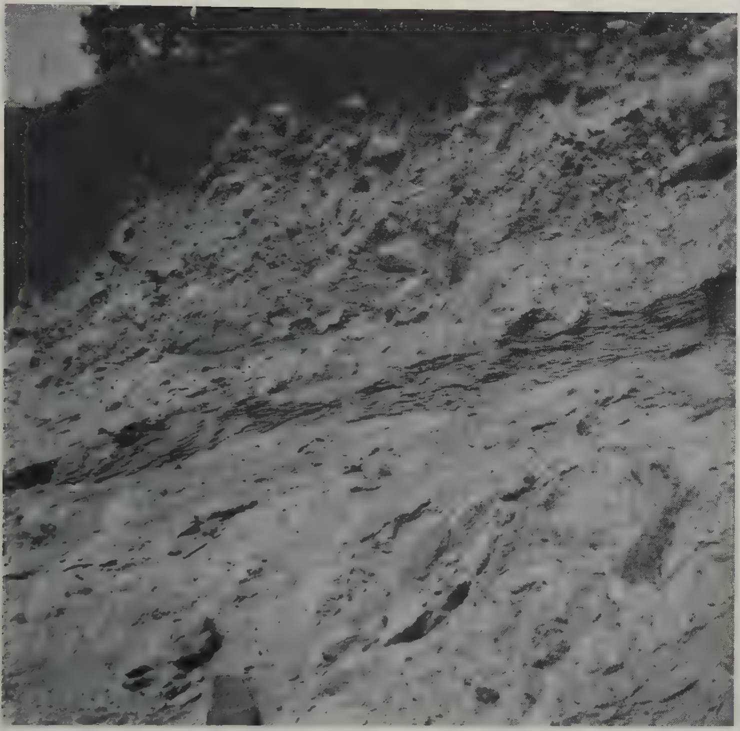


Foto H. Möller 1959.

Fig. 13. Ett avsnitt från profilen i fig. 12. Överst ytskikt med svallad morän, därunder pressad bottenmorän utan linser. Under denna följer löst lagrad linsförande morän med en utsträckt lins (eller ett lager) av strömskiktad grovmo (mitt på bilden).

A detail from the section in fig. 12.

fanns ej i den återgivna profilen. Den stora grovmolinsen (eller -lagret) var vackert strömskiktad. Fig. 13 visar ett avsnitt av skärningen med den strömskiktade grovmon överlagrad av lös linsförande morän samt den övre pressade bottenmoränen, vilken helt saknade linser av sorterat material. Den undre moränen mellan längdmåtten 22—52 m i profilen saknade likaledes dylika linser. Detta tyder på att den avsatts innan uppsmältningen började vid lokalen.

I flera ovan omtalade fall har lagerföljder med linser av sorterat material i morän antagits bildade i samband med isframstötar över tidigare avsatta sediment. Även vid de små framstötar, som isranden kan ha gjort under avsmältningen när de små ändmoränerna av årsmoräntyp (De Geer 1932; 1940, p. 120) bildades, kan sorterat material ha inlagrats i morän. I ändmoränryggarna synes partier med linser av sorterat material icke vara ovanliga. Sådana har iakttagits både i Stockholmstraktens ändmoräner och i exakt samma typ av ändmoräner vid Boden (jfr även Hoppe 1948, pp. 13 f.).

En icke tidigare nämnd företeelse är de tunna (av storleksordningen 1/2 cm) mantlar av relativt sorterad sand-mo, som man ofta finner i direkt kontakt med block i moränavlagringar. Mantlarna kan omsluta större eller mindre del av blockytan. Dessa mantlar tycks vara särskilt vanliga i moräner där vanliga linser av sorterat material förekommer. Men även i morän utan sådana linser förekommer dylika mantlar. Hur har dessa bildats? För det första måste de ha bildats innan moränen, som närmast omsluter dem, smälte fram ur isen. En mantel, som ingår i ett av en levande is avlastat moränparti, måste antagas bildad omedelbart innan partiet ifråga frigjordes från isen, ty under en längre transport i isen skulle manteln knappast ha bevarats intakt. Tydligt är att det måste ha funnits smältvatten i direkt anslutning till de blockytor, som omslutes av mantlar. I en rörlig is finns i varje punkt ett visst tryck. Om man teoretiskt tänker sig ett i en sådan is ingående parti av ren is, i vilken ett stenblock ligger inbäddat, så är trycket icke lika i alla punkter. Isen är plastisk och blocket kan betraktas som en relativt sett odeformerbar kropp. Tryck i isen, som från ett tryckhöjningscentrum fortplantas mot blocket, avlastas icke i detta utan fortplantas genom blocket. Då blockets kompressibilitet är avsevärt lägre än isens, kommer tryckfortplantningen genom blocket, i enlighet med den fysikaliska elasticitetsteorin, att ge en tryckförhöjning i gränsytan mellan blocket och isen i förhållande till trycket i längre ut från blocket belägna punkter. Denna tryckförhöjning erhålles i alla riktningar utom i den primära tryckhöjningens. Då smältpunkten för is sjunker med stigande tryck kan alltså isskikt i en smal mantelzon närmast intill blockytor under vissa förhållanden ha smält inne i omgivande is. I så uppkomna mantelrum kan smältvattnet i viss utsträckning ha sorterat frigjort moränmaterial. På så sätt kan tunna mantelskikt av sorterat material ha inneslutits i den omgivande isens osorterade moränmassa när denna avlastades.

Speciella företeelser vid lokal 1

I skärningen vid lokal 1 förekom dels ett tunt grusskikt, dels ett parti med finmoig-mjälig morän av speciell typ, vilka båda icke har något samband med lälinsmoränen. Fig. 2, 14 och 15 visar hur grusskiktet och det nämnda moränpartiet låg i lagerföljden. Det i den normala moränen inbäddade moränpartiet var mycket hårt packat. I övre delen var det uppdelat i mer eller mindre tydliga horisontella skikt av storleksordningen 1—3 cm. Skiktningen framträdde i vertikala snitt (fig. 15). Grundmassan i hela partiet utgjordes av finmo och mjäla. I partiets undre hälft var grövre fraktioner (grovmo-grus) jämnt fördelade i grundmassan, d. v. s. jordarten var genomgående osorterad. Sten och block saknades i hela partiet. I den övre hälften av detta växellagrade skikt, i vilka den finmoiga-mjäliga grundmassan var endast svagt bemängd med grövre fraktioner, med skikt, i vilka inslaget av dessa fraktioner var betydligt större (av storleksordningen 30—40 viktprocent). I oregelbundet fördelade småpartier var inslaget av grövre fraktioner särskilt koncentrerat. I vissa delar var skiktningen mycket diffus. Kurvan för prov 92 (fig. 16) visar sammansättningen av ett sådant otydligt skiktat parti. Kurvan ger genom knycken vid 0.06 mm ett uttryck för att provet är sammansatt av en finkornig grupp (ler-fin-

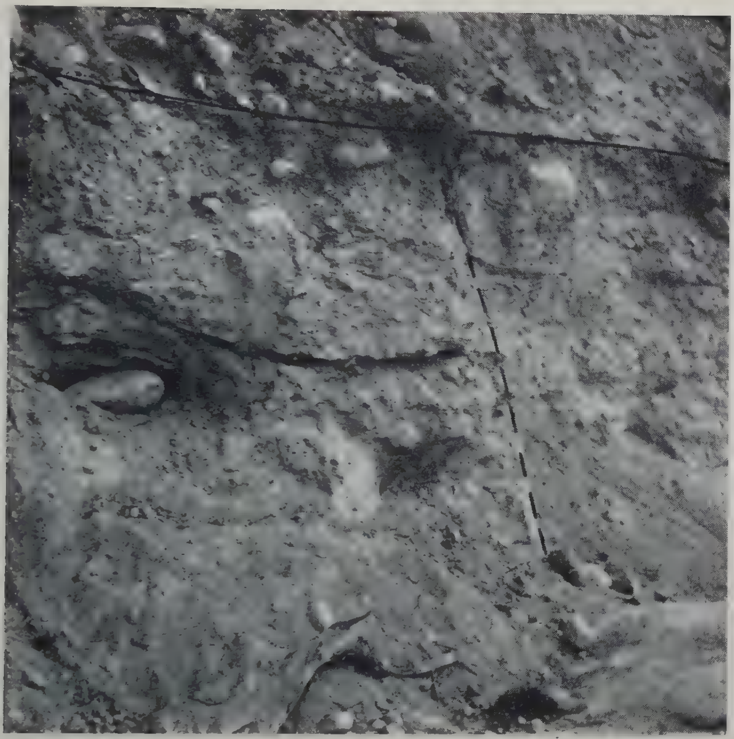


Foto H. Möller 1959.

Fig. 14. Ett avsnitt av profilen vid lokal 1 (se fig. 2). Det svagt böjda mörka skiktet på bildens vänstra hälft är grusskiktet mellan längdmåtten 58 och 60 m i profilen fig. 2. Det på denna medtagna vinkelsnittet i VNV—OSO är skymt på bilden. Den streckade linjen markerar hörnet vid längdmåttet 60 m. I bakgrunden till höger syns grusskiktets fortsättning som ett mörkt skikt i den här 2 m mot OSO förskjutna väggen (60—62 m i fig. 2). Heldragen linje markerar markytan, därovan upplagda jordmassor. Kurvan för prov 66 i fig. 16 visar grusskiktets sammansättning.

A detail from the section at locality 1 (fig. 2). The dark thin stratum is the stratum of gravel between 58 and 60 m in fig. 2. The broken line marks the corner at 60 m in fig. 2. The continuous line marks the soil surface. Above it the soil is dug over.

mo) och en grovkornig grupp (grovmo-fingrus) utan kontinuerlig övergång mellan dessa båda grupper. Jordarten är varken en normal osorterad morän eller ett normalt sorterat sediment. Eftersom hela partiet otvivelaktigt måste ha transporterats av isen, tillhör det genetiskt sett moränavlagringarna. I enlighet med den på sid. 173—174 förda diskussionen kan det insprängda partiet betecknas som ofullständig morän.

De nämnda förhållandena kan tolkas på två sätt.

1. Isen har tagit upp ett parti från en sorterad finkornig avlagring (som möjligen varit skiktad) och transporterat detta parti en kort sträcka, varvid grövre fraktioner tillförts. Förvånande är dock, att dessa i vissa delar av partiet var skiktvis koncentrerade. Möjligen återspeglar detta en skiktstruktur i det isparti som tog upp och transporterade den sorterade avlagringen.
2. Isen har tagit upp en skålla (frusen) och transporterat denna, varvid den

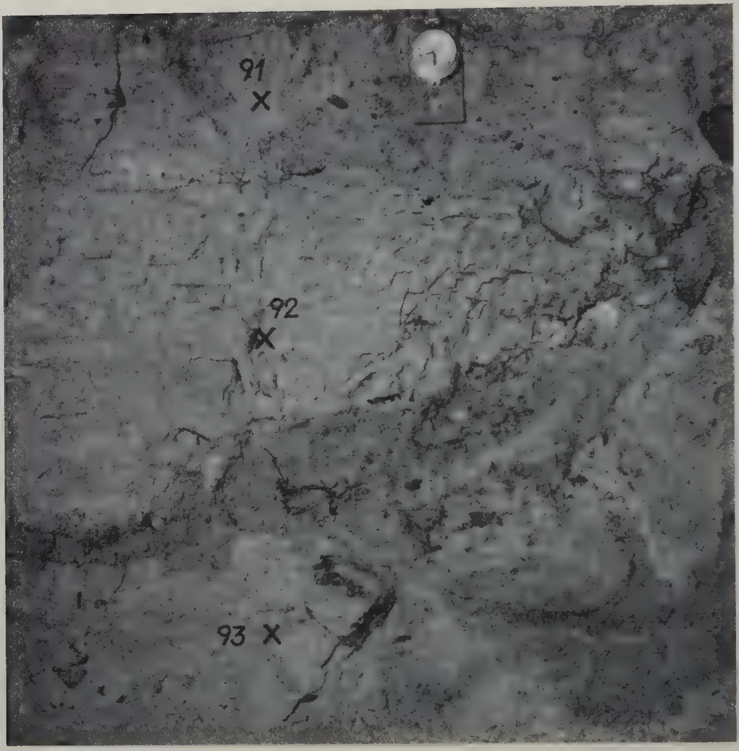


Foto H. Möller 1959

Fig. 15. Detalj från det i VNV—OSO utsträckta snittet i profilen vid lokal 1 (se fig. 2). Det ljusa, åt höger avsmalnande partiet i bildens mitt är den mycket hårt packade, ofullständiga finmoiga-mjäliga moränen, vilken i övre delen är uppdelad i mer eller mindre tydliga horisontella skikt. Detta parti ligger direkt på det några cm mäktiga grusskiktet och är inneslutet i den sandiga-moiga moränen. Proverna 91, 92 och 93 redovisas i fig. 16.

A detail from the section at locality 1 (fig. 2). The light portion in the middle of the figure is the very hard packed till with very fine sand and silt. This till is not really unassorted (compare the curve 92 in fig. 16) Either it originates from a sorted fine grained sediment, which has received an addition of coarser material (fine sand-gravel) during transport in the ice, or it is a portion of an incompletely sorted sediment transported as a »boulder» in the ice.

visserligen blivit hårt sammanpressad men icke erhållit materialtillskott eller i övrigt blivit nämnvärt förändrad. Skållan skulle alltså härröra från en avlagring med den sammansättning det insprängda partiet har. Ett sediment av denna typ kan kanske ha avsatts vid oroliga sedimentationsförhållanden, t. ex. i israndnära miljö.

Oavsett vilken tolkning man vill hålla för troligast, så är det insprängda av finmo och mjäla dominerade partiet ett tecken på att isen i slutskedet oscillerat i Stockholmsområdet, varvid finkorniga sediment avsatts framför isranden och sedan överskridits av isen. Som exempel på liknande bildningar från andra trakter kan de av G. Lundqvist (1951, p. 33) omtalade tunna ler- eller mjälalagren, som ibland påträffas i områden över H.K., nämnas. Dessa lager har en viss halt av grövre fraktioner, vilka enligt G. Lundqvist »tydligen bakats in i sedimentmassan genom isens arbete». Det skulle närmast röra sig om sedi-

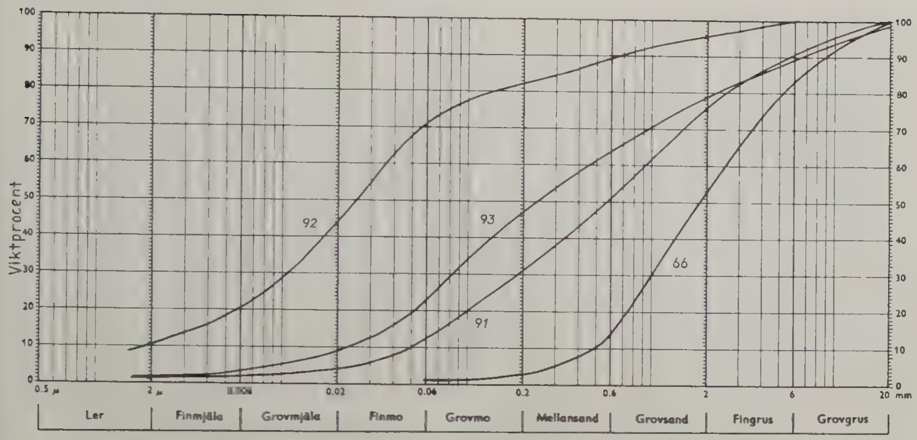


Fig. 16. Kumulativdiagram över korngruppsfördelningen i jordprover från lokal 1 (se fig. 2 och 15). Kurvan för prov 66 visar grusskiktets sorteringsgrad. Kurvan för prov 92 ger genom knycken vid 0.06 mm ett uttryck för att provet är sammansatt av en finkornig grupp och en grovkornig grupp utan kontinuerlig övergång.

Cumulative diagram showing the composition of samples taken in the section at locality 1 (compare figs 2 and 15).

ment, som avsatts i en liten sjö framför iskanten och som sedan överskridits av isen. I beskrivningen till kartbladet Säter (G. Lundqvist 1953, p. 54) omtalas en liten skärning, i vilken ett 20 cm mäktigt lager med »lerig-mjälig morän?» på 0.5 m djup låg inbäddat i den för trakten normala moränen. G. Lundqvist (l.c.) antar, att det är ett sedimentlager, som pressats och utvalsats.

Det erbjuder icke några större svårigheter att i stora drag förstå uppkomsten av det vid lokal 1 inbäddade partiet med ofullständig finmoig-mjälig morän (se ovan). Däremot blir det mera komplicerat när man betraktar hela lagerföljden i det avsnitt av skärningen där partiet låg inbäddat. Partiets läge i förhållande till övriga lager framgår av fig. 2. Fig. 14 och 15 visar mera detaljerat hur grusskiktet och partiet med ofullständig finmoig-mjälig morän såg ut i skärningen. Grusskiktet mellan längdmåtten 56 och 64 m var väl sorterat (prov 66, fig. 16). Det vid längdmåttet 60 m vinkelställda snittet (VNV—OSO) visade, att skiktet här hade en planutsträckning på mer än 2 m. N om partiet med den hårt packade ofullständiga finmoiga-mjäliga moränen skar grusskiktet snett uppåt genom den pressade sandiga-moiga moränen (fig. 2 och 14). En del i det förra ingående små stenar satt här så hårt fastklämda, att man endast med svårighet kunde ta bort dem. Mellan längdmåtten 58 och 60 m samt i det vinkelställda snittet överlagrades grusskiktet direkt av partiet med ofullständig finmoig-mjälig morän. Denna i sin tur överlagrades mellan längdmåtten 58 och 59.5 m av pressad sandig-moig morän. I det vinkelställda snittet framträdde icke någon presstruktur i den överlagrande moränen. Orsaken torde endast vara, att denna i detta begränsade avsnitt hade något lägre halt av finmaterial (prov 91, fig. 16). Den var emellertid hårt packad och icke svallad samt stod i direkt samband med den nämnda pressade sandiga-moiga moränen. Mellan längdmåtten 58.5 m och 64 m vilade grusskiktet på en sandig-moig morän (prov 93, fig. 16). Denna var medelhård-lös samt saknade linser och får betraktas som en övergångszon till den därunder liggande lälinsmoränen.

Det kanske mest förbryllande i den beskrivna lagerföljden är grusskiktet. Lagerföljden påminner onekligen om de av Richter (1929) beskrivna skärningarna med små skållor och tunna skikt, som tagits upp från isens underlag, samt utdragna sandlinser, allt inlagrat i en till synes enhetlig morän (jfr även Slater 1927). Dylika lagerföljder återspeglar isens struktur. Den troligaste förklaringen till grusskiktet vid lokal 1 synes dock vara, att detta avsatts på en frilagd yta. som sedan överskridits av en oscillerande is, vilken medförde partiet med ofullständig finmoig-mjälig morän (skålla).

De linsförande moränavlagringarnas praktiska betydelse

Förekomsten av genomsläppligt sorterat material under eller i morän kan ha stor betydelse för den nutida vattencirkulationen i marken (Hörner 1944). Bland de ovan omtalade moränavlagringarna kan vissa grupper, i vilka grus-, sand- och molinser ofta uppträder, urskiljas. Den praktiska betydelsen härav bör uppmärksammas. Den torde vara av intresse bl. a. för den skogliga forskningen.

Dödismoräner (ablationsmoräner) ovanför högsta kustlinjen är i regel lätt igenkännliga på ytformerna. I dessa avlagringar är linser av sorterat material särskilt vanliga (se t. ex. Mannerfelt 1945). Härtill kommer att dödismoränerna i regel är ganska grovkorniga och därför relativt sett ganska genomsläppliga. På samma sätt förhåller det sig med typiska ytmoräner, i vilka genomsläppliga linser också förekommer tämligen allmänt. I vissa delar av landet är dylika ytmoräner i stort sett bundna till dalbottnarna och sluttningarna, medan däremot moränen på höjderna huvudsakligen är tät morän av pinnmotyp (G. Lundqvist 1940, pp. 36 ff.; 1957, p. 323). Man bör även uppmärksamma, att rikligt med linser av genomsläppligt material kan uppträda i moränavlagringar i anslutning till isälvsstråk både över och under högsta kustlinjen (jfr sid. 189). Genomsläppliga linser synes också vara ganska vanliga i de små ändmoränryggarna av årsmoräntyp. Sådana lägesbundna komplexa avlagringar, som påträffats i Stockholmstrakten och som i denna uppsats sammanförts under beteckningen lälinsmoräner, synes vara en vanlig företeelse även i andra delar av landet (jfr G. Lundqvist 1953, p. 54 och J. Lundqvist 1958, p. 61). Här bör också de av Hessland (1942, 1943) och Björsjö (1949) uppmärksammade »lämoränerna» (Björsjö) i Bohuslän nämnas. I kuperade områden under högsta kustlinjen synes chanserna för att genomsläppligt sorterat material skall ingå i moränavlagringarna vara mycket större på läsidor och i lälägen, sett i förhållande till de sista isrörelseriktningarna, än i andra lägen.

I lälägen är moränavlagringarna oftast löst lagrade. Vidare har de vanligen lägre halt av finmo-ler (se fig. 7) än den packade bottenmoränen på t. ex. stötsidorna eller i övriga icke lälägen. Detta gör, att rötter och rottrådar lättare kan tränga ned i de förstnämnda moränavlagringarna. I skärningar med ytlig bottenmorän kan man se, att rottrådarna brett ut sig åt sidorna och bildat en tät filt i gränsskiktet mellan den löst lagrade svallade moränen (inom här undersökt område normalt 2—3 dm, högst 4 dm mäktig) och den hårt packade bottenmoränen. I moränsluttningarna avrinner det från ytan nedsipprande vattnet (ytvattnet) till stor del just i detta gränsskikt. De heldragna kurvorna i diagrammet fig. 7 kan representera den normala osvallade bottenmoränen inom urbergsområden (pinnmo). Sådan morän är föga genomsläpplig. Dess k-värde är mindre än 0.1 cm/tim (vid normaltrycket 2 kg/cm^2).

Till de praktiskt arbetande kvartärgeologernas uppgifter i dagens Sverige hör omfattande undersökningar i samband med vattenkraftens utbyggnad. Därvid gäller det bl. a., att inom begränsade ytor finna minst 5—10 m mäktig morän av viss typ, s. k. tätjord, för dammbyggnader. Denna tätjord får bl. a. icke vara oenhetligt uppbyggd med större linser av sorterat material eller större inslag av ofullständigt sorterat material. Tätjorden måste vidare ha en viss halt av finmaterial (finmo-ler). Med vetskap om de bildningar, som här kallats lälinsmorän, bör man alltså undvika att sätta igång de dyrbara tätjordsundersökningarna i lälägen. Erfarenheten från arbetena i Norrland visar också, att tätjordsundersökningar i lälägen ofta gett negativt resultat. Moränen kan ha varit utmärkt som tätjord i de övre lagren (t. ex. ned till 3—4 m under ytan), men linsförande moränlager på djupare nivå har gjort att området blivit utslaget.

Litteratur

GFF = Geologiska Föreningens i Stockholm Förhandlingar.
SGU = Sveriges Geologiska undersökning, Stockholm.

Ahlmann, H. W:son, 1938: Über das Entstehen von Toteis. — GFF 60.

Beskow, G., 1935: Praktiska och kvartärgeologiska resultat av grusinventeringen i Norrbottens län. — GFF 57.

Björsjö, N., 1949: Israndstudier i södra Bohuslän. — SGU, C 504.

Carol, H., 1947: The formation of Roches Moutonnées. — Journal of glaciology, 2. London.

Charlesworth, J. K., 1957: The Quaternary Era. I. — London.

De Geer, G., 1932: Stockholmstraktens kvartärgeologi. — SGU, Ba 12.

— 1940: Geochronologia Suecica Principles. — Kungl. Svenska Vetenskapsakademiens Handl. Tredje serien, 18. Stockholm.

Erdmann, Edvard, 1871: Kartbladet Rydboholm. — SGU, Aa 44.

Flint, R. F., 1947: Glacial geology and the Pleistocene Epoch. — New York och London.

— 1957: Glacial and Pleistocene Geology. — New York och London.

Frödin, Gustaf, 1956: Isströmssuccessionen på Uplandshalvön jämte försök till korrelation med Ålands och Åbolands skärgård. — Geographica 32. Uppsala.

Granlund, Erik, † 1943: Beskrivning till jordartskarta över Västerbottens län nedanför odlingsgränsen. — SGU, Ca 26.

Hessland, I., 1942: Über Massenvorkommen von *Corallina officinales* L. — Senckenbergiana, 25. Frankfurt a. M.

— 1943: Marine Schalenablagerung Nord-Bohusläns. — Bull. Geol. Inst. Upsala, 31, Uppsala 1946.

Holmes, Chauncy D., 1949: Glacial erosion and sedimentation. — Pleistocene research. Bull. Geol. Soc. of America, 60. New York.

Hoppe, G., 1948: Isrecessionen från Norrbottens kustland i belysning av de glaciala formelementen. — Geographica, 20. Uppsala.

Hörner, N. G., 1944: Moräns mekaniska sammansättning. — GFF 66.

— 1946: Uppsalamoränens finfraktioner. — GFF 68.

Johnsson, G., 1956: Glacialmorfologiska studier i södra Sverige. — Medd. Lunds Univ. Geogr. Instit. Lund.

Järnefors, B., 1958: Beskrivning till jordartskarta över Uppsalatrakten. — SGU, Ba 15.

v. Klebelsberg, R., 1948: Handbuch der Gletscherkunde und Glazialgeologie. I. — Wien.

Ljungner, E., 1930: Spaltentektonik und Morphologie der schwedischen Skagerrak-Küste. — Bull. Geol. Inst. Upsala, 21. Uppsala.

— 1945: Den sista nordiska nedisningens förlopp. — GFF, 67.

Lundqvist, G., 1940, Bergslagens minerogena jordarter. — SGU, C 433.

— 1943: Norrlands jordarter. — SGU, C 457.

— 1948: Blockens orientering i olika jordarter. — SGU, C 497.

— 1951: Beskrivning till jordartskarta över Kopparbergs län. — SGU, Ca 21.

— 1953: »Jordlagren» i Beskrivning till kartbladet Säter av S. Hjelmqvist och G. Lundqvist. — SGU, Aa 194.

— 1955: Räffelriktningar och rullstensåsar. — GFF 77.

— 1957: »De kvartära bildningarna» i Sveriges geologi 3:e uppl. av Magnusson, N. H., Lundqvist, G. och Granlund, E. — Stockholm.

— 1958: Beskrivning till jordartskarta över Sverige. — SGU, Ba 17.

Lundqvist, Jan, 1958: Beskrivning till jordartskarta över Värmlands län. — SGU, Ca 38.

Mannerfelt, C. M:son, 1945: Några glacialgeologiska formelement och deras vittnesbörd om inlandsisens avsmältningsmekanik i svensk och norsk fjällterräng. — Geogr. Annaler. Stockholm.

Munthe, H., 1906: Beskrifning till kartbladet Tidaholm. — SGU, Aa 125.

— m. fl. 1928: Beskrivning till kartbladet Skövde. — SGU, Aa 121.

Möller, H., 1959: Från nordostis till lågbaltisk is. — SGU, C 566.

von Post, L., 1929: »Kvartära bildningar» i Beskrivning till kartbladet Säffle av Nils h. Magnusson och Lennart von Post. — SGU, Aa 167.

Richter, K., 1929: Studien über fossile Gletscherstruktur. — Z. Gletscherkunde 17. Leipzig.

Slater, G., 1927: The structure of the disturbed deposits of Möens Klint, Denmark. — Transact. Roy. Soc. Edinburgh, 55.

Strömberg, Bo och Sundius, Karin, 1956: Studier av isräfflor och glacialskulptur i Stockholms skärgård. — Ymer, 76.

Terasmäe, I. och J., 1951: Om sedimentationens beroende av landisens bottenrörelser. — GFF, 73.

Westergård, A. H., 1934: En kvartär stromatolitkalksten från Bohuslän. — SGU, C 381.

The Lower Didymograptus Shales of the Flagabro Drilling Core

By

TORSTEN E. TJERNVIK

Abstract: In the core section described the basal strata are very poor in graptolites. On the other hand, they have yielded trilobite species characteristic of the Lower Planilimbata Limestone. Most part of these shales have been included with the zone of *Tetragraptus phyllograptoides*.

The zone of *Didymograptus balticus* contains a rich graptolite fauna described by Törnquist.

In the shales with *Phyllograptus densus* the Norwegian zone of *P. angustifolius elongatus* is well developed, and has yielded several graptolite forms new to Sweden.

The top strata of the Lower Didymograptus Shales (with *Isograptus gibberulus*, etc.) are not represented in the core. They have been exposed through diggings carried out at the Flagabro rivulet. Preliminary notes on the graptolite fauna of these shales are added to the description of the core.

Introduction

The Arenigian of Sweden often displays a sequence of limestones in which layers of clayey shales are of little consequence. However, in the provinces of Jämtland, Dalarna, Västergötland, and Skåne (Scania) these limestones change — to a more or less high extent — into graptolite bearing shales called the Lower Didymograptus Shales.

In the spring and summer of 1958 the present writer had the opportunity of studying the Lower Didymograptus Shales at Flagabro in south-eastern Skåne. A drilling core obtained at the locality was examined, and supplementary data were secured from outcrops and diggings in the vicinity of the farm.

In this paper the core only is described.

Previous Work

The first report on the Lower Didymograptus Shales of Flagabro was made by Törnquist (1875, p. 46). At the rivulet below the mill of the farm he encountered alum shales with *Dictyonema f. flabelliforme,* overlain farther to the south-west by grey clayey shales containing species of *Didymograptus, Tetragraptus,* and *Phyllograptus.*

In his papers of 1901 (p. 3) and 1904 Törnquist gave a more detailed account of the clayey shales exposed at the locality. The stratigraphical subdivisions distinguished by Törnquist, and the fossils collected by him, were as follows:

1. Zone of *Tetragraptus phyllograptoides.* — Shales of a light greenish colour, almost devoid of fossils. From some darker seams *Tetragraptus phyllograptoides* Törnquist, *Didymograptus undulatus* Törnquist, and *D. constrictus* Hall were collected.

2. Zone of *Didymograptus balticus.* — Dark shales with a rich graptolite fauna comprising *Didymograptus balticus* Tullberg, *D. geometricus* Törnquist (common), *D. constrictus* Hall, *D. suecicus* Tullberg, *Tetragraptus quadribrachiatus* Hall, *Schizograptus reticulatus* Nicholson, *S. rotans* Törnquist, *S. ambiguus* Törnquist, *Temnograptus multiplex* Nicholson, and (?) *Clonograptus subtilis* Törnquist.

3. Zone of *Phyllograptus densus.* — Dark shales crowded with specimens of *Phyllograptus densus* Törnquist. Other species obtained were *Didymograptus suecicus* (abundant), *D. praenuntius* Törnquist (abundant), and *Tetragraptus pendens praesagus* Törnquist.

4. Zone of *Isograptus gibberulus.* — A band of grey or greenish shales lying immediately beneath the Orthoceratite Limestone belongs to this zone (1904, p. 3). It contains *Didymograptus mobergi* Törnquist and *Azygograptus suecicus* Moberg.

At present these shales are but poorly exposed at the locality.

The Core

In 1941 a core drilling was carried out at a small limestone quarry situated 500 m south-west of the Flagabro farmhouse. It penetrated the basal beds of the Arenigian Orthoceratite Limestone, and passed through the underlying Lower Didymograptus Shales and the Tremadocian beds. After entering the top strata of the Upper Cambrian alum shales the boring was interrupted at a depth of 54.33 m. The diameter of the core is 20 cm.

The core was acquired by the Palaeontological Institution of Lund, and was made ready for an examination by Engineer E. Köster in 1956. He divided the core into portions being, as a rule, 5 cm thick. The portions were split, and the fossils encountered were labelled and stored. On this material — in part unfortunately small — the author's description of the core is based.

The lower part of the core section, comprising the Dictyonema Shales and the overlying Ceratopyge Beds, was described by the present writer in his paper "The Tremadocian beds at Flagabro in south-eastern Scania (Sweden)", published in Geologiska Föreningens Förhandlingar, 1958.

The Lower Didymograptus Shales, which are dealt with in this paper, rest upon the Tremadocian Ceratopyge Limestone. According to the drilling journal they have a total thickness of about 36 metres. These large dimensions are due, however, to a partial repetition of the sequence caused by a fault. The real thickness of the Lower Didymograptus Shales at this locality seems to be about 23 metres.

The core is not complete. Its uppermost part had suffered very great losses during the drilling, and was not preserved. In the portion secured the top strata are dislocated by a fault. The usable part of the core section extends upwards to the shales with *Phyllograptus angustifolius elongatus* Bulman. Accordingly, the uppermost strata with *Isograptus gibberulus* Moberg, etc., are not represented in the core. Furthermore, a portion of the shales with *Phyllograptus densus* and *Didymograptus gracilis* is lacking owing to another fault.

Description of the core

The section obtained is described below, and illustrated in text-figs. 1 and 2. The drawings of the section are combined with diagrams showing the vertical distribution of the graptolite, trilobite, and conodont species, as well as the number of specimens encountered.

The fossils recorded from the core are kept in the museum of the Palaeontological Institution of Lund.

Tremadocian

B 2. Ceratopyge Limestone (41.14—41.46 m) treated in Tjernvik, 1958 (pp. 271 and 274).

Arenigian

Lower Didymograptus Shales. — Thickness of the section described about 16.75 m (24.40—41.14 m).

HUNNEBERG STAGE

Remarks. — A transgression indicates the beginning of the Arenigian. The basal limestones of this series (and of the Hunneberg Stage) have a considerably wider regional distribution than the Ceratopyge Limestone. The transgression expands during the middle of the Hunneberg Age. Certainly, the occurrence of the shales with *Tetragraptus phyllograptoides* is restricted to Skåne, southwestern Västergötland, and western Jämtland. Yet, the corresponding limestone beds with *Plesiomegalaspis planilimbata* are well represented in almost all Ordovician districts of Sweden.

The shales with *Didymograptus balticus* terminate the Hunneberg Stage. They are well developed in Skåne and at Hunneberg in Västergötland. However, they seem to have been laid down during a regression. In fact, corresponding limestones are lacking in most part of Sweden — at least they are unknown to the present author.

The core. — From the bottom strata of the Lower Didymograptus Shales but a few fragments of graptolites and trilobites have been secured. These strata, which have a thickness of about 7 metres, extend from the upper surface of the Ceratopyge Limestone to the 34.10 m level of the core. They can be divided into two lithological units, called in the following A 1 and A 2.

A 1. Thickness about 1.5 m (39.67—41.14 m).

The lowest shale unit rests upon the uneven and glauconite-impregnated upper surface of the Ceratopyge Limestone. It extends to a bedding surface of shale covered by glauconite, and overlain by a thin bed of glauconitiferous limestone.

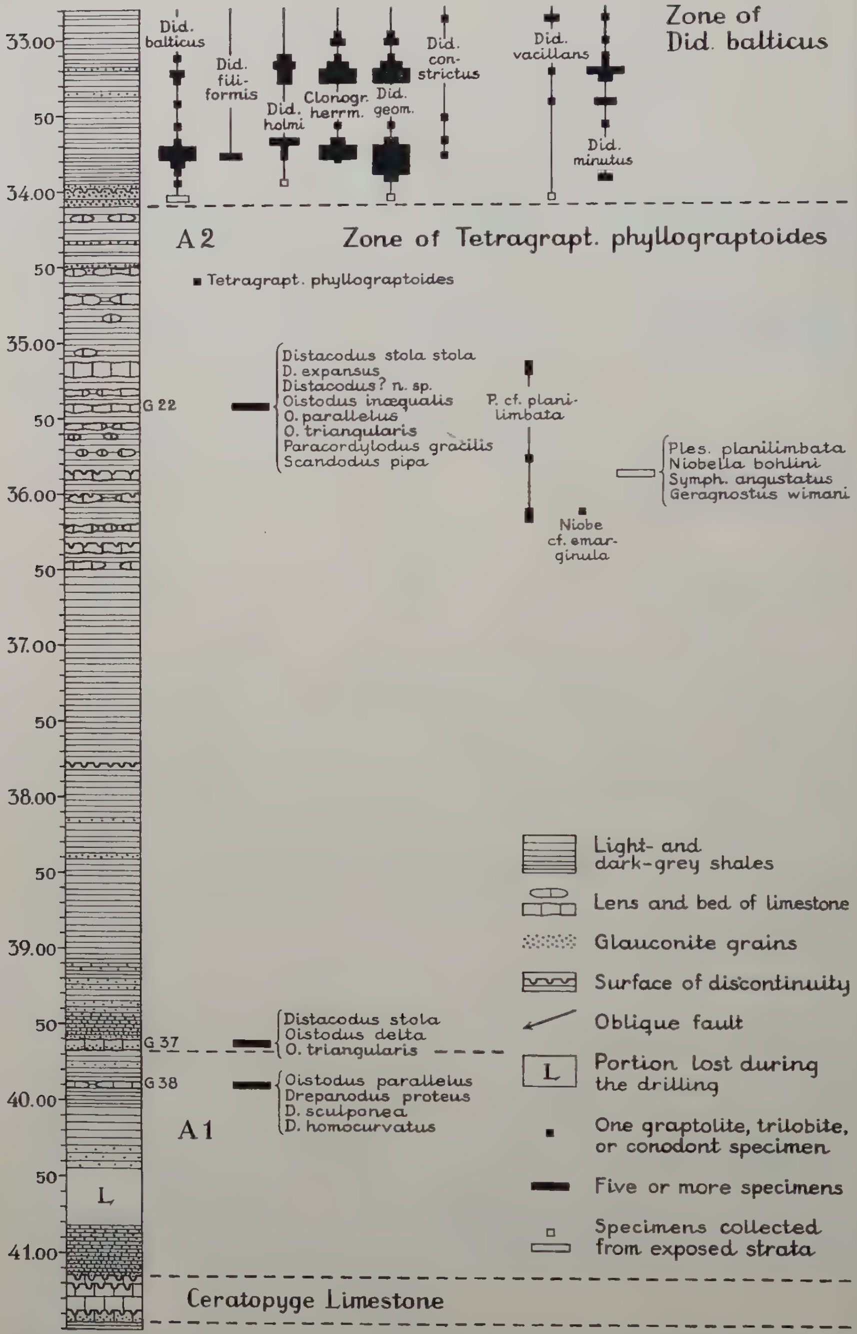


Fig. 1. The Flagabro drilling core. Vertical distribution and number of graptolite, trilobite, and conodont specimens encountered in the lower strata of the Lower Didymograptus Shales.

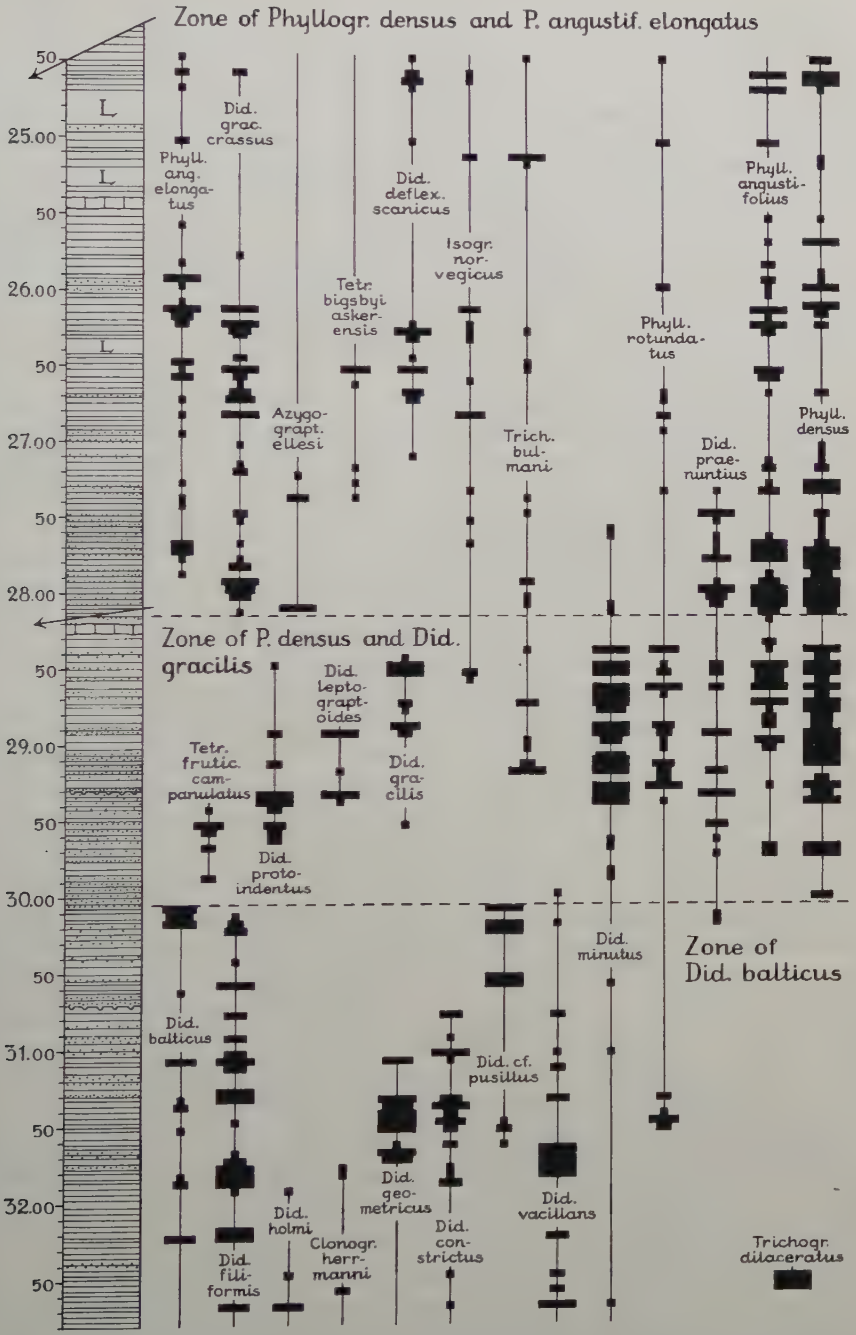


Fig. 2. The Flagabro drilling core. Vertical distribution and number of graptolite specimens encountered in the middle strata of the Lower Didymograptus Shales.

The lowermost strata of the unit consist of very dark shales which are rich in grains of glauconite and phosphorite, and contain lumps or chrystals of pyrite. They are overlain by grey shales with scattered grains of glauconite. A portion of these shales, about 0.4 m thick, has been lost during the drilling. The uppermost strata are dark-coloured, and contain a thin bed of light-grey limestone. The latter probably indicates a reduced depth of water during the deposition of the top layers of the unit.

Small inarticulate brachiopods, *Lingulella* spp., *Acrotreta* spp., *Obolella?* sp., and *Broeggeria* sp. abound in the shales. A couple of small hyolithids were found at the 40.90 m level, and the top beds have yielded a few specimens of a phyllocarid: *Caryocaris?* sp.

No graptolites at all were encountered.

Conodonts were sought for on all slabs of shale, yet, with little success; the few specimens obtained are fragmentary and indeterminable as to the species. Better specimens were secured, however, from the thin limestone bed (numbered *G 38*) which is found in the top strata. According to determination kindly carried out by Dr. M. Lindström, Lund, these conodonts belong to the following species: *Oistodus parallelus* Pander, *Drepanodus sculponea* Lindström, *D. proteus* Lindström, *D. homocurvatus* Lindström, and *Acodus* aff. *Distacodus stola* Lindström. In the opinion of Dr. Lindström they are of post-Tremadocian age, but give no evidence of the exact stratigraphical level of the bed.

From the Flagabro exposures, examined by Törnquist and the writer, no information can be gathered as to the said stratigraphical level. The shales of the unit A 1, as well as those of the lower part of A 2, are lacking on the banks and the bottom of the Flagabro rivulet. They have been cut off by a fault.

A 2. Zone of *Tetragraptus phyllograptoides.* — Thickness about 5.5 m (34.10—39.67 m).

The second unit is made up of shales, alternately dark- and light-coloured. The basal strata are almost black and rich in glauconite grains. In the overlying shales — that is in by far the greater part of the zone — glauconite and phosphorite grains are scarce; they are found at a few levels only. At the 37.80 m level a bedding surface is covered with a film of glauconite. It indicates that the unit can possibly be divided into two subdivisions.

At the very base of the unit of A 2 there is a thin bed of grey, glauconitiferous limestone, called *G 37*. It is devoid of macro-fossils. On the other hand, some conodont species have been encountered in the rock. They are dealt with below, in connection with the other fossils secured from the shales and the limestones of the unit.

Above the 36.50 m level the shales contain a large number of scattered thin beds and lenses of grey limestone. They indicate shallow water conditions during the sedimentation of the upper strata of the unit.

Inarticulate brachiopods, *Lingulella* spp., *Acrotreta* spp., and *Broeggeria* sp. occur throughout the shales; they are, however, much more scarce than in the strata of the underlying subdivision (A 1). On the contrary, *Caryocaris* sp.

abounds, especially in the dark-coloured shales of the unit. Furthermore, a few valves of *Nanorthis?* sp. have been found.

Of interest are some fragments of large trilobites secured from the upper shale strata (cf. text-fig. 1). They seem to belong to *Plesiomegalaspis planilimbata* (Angelin) and *Niobe emarginula* Angelin. Better trilobite specimens have been collected from the exposures at the Flagabro rivulet. In a bed of grey limestone occurring in the upper part of the unit of A 2 the following species have been encountered: *Plesiomegalaspis planilimbata, Niobella bohlini* Tjernvik, *Niobe* cf. *emarginula, Symphysurus angustatus* Sars & Boeck, and *Geragnostus wimani* Tjernvik. *Symphysurus angustatus* has a fairly wide vertical range. The other species are index fossils for the Lower Planilimbata Limestone (zone of *Plesiomegalaspis planilimbata*) which has a very large regional distribution in Sweden. Hitherto, it was not known from Skåne.

The scarce graptolite specimens occurring in the shales have evidently escaped the attention of Engineer E. Köster on splitting the core. In consequence, the slabs kept for a renewed examination of the shales are regrettably few, and have yielded only about twenty small fragments of graptolites. Most of these fragments belong to indeterminable species of *Clonograptus* and *Didymograptus*, and are of small stratigraphical value. However, at the 34.60 m level — that is in the uppermost part of the unit — the proximal portion of a *Tetragraptus* has been obtained. The broad rhabdosome and the vertical stipes of the specimen make possible an identification with *T. phyllograptoides* Törnquist.

At the Flagabro rivulet the exposed dark shales with *Didymograptus balticus* Tullberg are underlain by weathered, light-grey shales rich in lenses and thin beds of limestone. These light-coloured strata have a maximal thickness of 3 metres. They have been cut off by a fault, and rest upon beds of trilobite bearing sandstone of Lower Cambrian age. Without any doubt, the light-grey shales and their limestones correspond to those strata of the core which belong to the upper part of the unit of A 2 (34.10 — approximately 37.00 m).

The outcropping strata are not easy of access. The chief part has been unearthed by the writer through digging at the bottom of the rivulet; a procedure that has obstructed the search for fossils. With exception of the abovementioned trilobite species the strata have yielded so far nothing but inarticulate brachiopods. However, these shales must be identical with those from which Törnquist collected specimens of *Tetragraptus phyllograptoides* and *Didymograptus undulatus* Törnquist (kept in the museum of the Paleontological Institution of Lund). He writes (Törnquist, 1901, p. 3):

> "The lowest portion of these shales are of a light greenish colour and almost devoid of fossils, but in some darker seams a few graptolite species have been found, belonging to the *zone of Tetragraptus phyllograptoides.* Upon them follow black shales including a rich fauna of graptolites. The species indicate the *zone of Didymograptus balticus,* being, for the most part, identical with those seen in the corresponding zone of Hunneberg."

A contradictory conclusion as to the stratigraphical level of the unit of A 2 has been drawn from the occurrence of some conodont species in the strata (cf. Tjernvik, 1958, p. 271). From the thin bed of glauconitiferous limestone called *G 37,* and situated at the base of the subdivision, Dr M. Lindström, Lund, has extracted and determined the following forms: *Distacodus stola* Lindström. *Oistodus delta* Lindström, and *O. triangularis* Lindström. In the opinion of Dr Lindström these conodonts prove that the bed — and, in consequence, the whole of the unit of A 2 — must be included with the zone of *Didymograptus balticus.*

In another limestone bed, *G 22,* from the upper part of the subdivision a conodont fauna more rich in species has been obtained. According to the kind determination by Dr M. Lindström it comprises: *Distacodus stola stola* Lindström, *D. expansus* (Graves & Ellison), *Distacodus?* n. sp. Lindström (1957, p. 165), *Oistodus inaequalis* Pander, *O. parallelus* Pander, *O. triangularis, Paracordylodus gracilis* Lindström, and *Scandodus pipa* Lindström. With the exception of *Oistodus inaequalis* and *Paracordylodus gracilis* (which indicate a lower stratigraphical level) the composition of the assemblage agrees well with that of the conodont fanuna encountered by Lindström (1957, p. 164) in the zone of *Didymograptus balticus* at Mossebo in Västergötland.

However, the graptolite fragment secured from the core, as well as the graptolite specimens collected by Törnquist from the exposures at Flagabro, seem to the present author to furnish a sufficient ground for including the unit of A 2 with the zone of *Tetragraptus phyllograptoides* and not with the zone of *Didymograptus balticus.*

Furthermore, the strata in question contain trilobite species which are index fossils for the Lower Planilimbata Limestone (Zone of *Plesiomegalaspis planilimbata*). This fact does not agree with another statement made by Lindström (1957, pp. 166 and 176) which signifies that the shales with *Didymograptus balticus* are younger than the Lower Planilimbata Limestone.

The upper boundary of the unit of A 2 has been drawn at the 34.10 m level. It corresponds to the base of a layer of glauconitiferous shale which in the exposures at Flagabro contains *Didymograptus balticus, D. vacillans,* and *D. geometricus.*

A 3. Zone of *Didymograptus balticus.* — Thickness about 4 m (30.05—34.10 m).

At the 34.00 m level a rich graptolite fauna turns up in the shales of the core. The species encountered prove that the strata extending to the 30.05 m level belong to the zone of *Didymograptus balticus.* These strata, which have a thickness of about 4 metres, consist entirely of shales; mostly dark-grey, with thin seams of almost black shale. Glauconite grains abound at the very base of the zone. Otherwise, they are scarce in the lower beds of the zone; in the upper strata, on the contrary, glauconite grains are fairly common.

In the exposures the lower boundary of the zone is pointed out by a thin layer of glauconite sand. It contains small nodules of glauconitiferous limestone with *Plesiomegalaspis planilimbata, Symphysurus augustatus, Cyclopyge gallica* Tjernvik, and *Pliomerops actinurus* (Dalman).

Twenty-four graptolite species or subspecies have been encountered in this part of the core. Many of the forms are known from the shales of the Hunneberg Mountain in Västergötland; the others from the Oslo Region. The vertical distribution of these species is the following (cf. text-figs. 1 and 2):

Didymograptus balticus Tullberg and *D. filiformis* Tullberg occur throughout the zone, and disappear just below its upper boundary. *Didymograptus holmi* Törnquist — at Hunneberg a member of the next older fauna –– reaches the middle of the unit. In the same beds *Clonograptus herrmanni* Monsen abounds at several levels. *Didymograptus geometricus* Törnquist, which is often the most frequent species, is found in the lower two thirds of the subdivision. In the upper strata it is associated with, and outlived by another small graptolite, probably identical with *D. pusillus* Tullberg. *D. constrictus* (J. Hall) has about the same vertical distribution as *D. geometricus.*

Some species or subspecies occur but sporadically. They are: *Didymograptus balticus vicinatus* Monsen, *D. vacillans attenuatus* Monsen, *D. flexilis* Monsen (33.10—33.15 m), *Tetragraptus bigsbyi* (J. Hall), *T. bigsbyi divergens* Monsen, *T.* aff. *astericus* Monsen (30.50—30.55 m), *Dichograptus octobrachiatus* (J. Hall), *Loganograptus kjerulfi* Herrmann, *Herrmannograptus regularis* (Törnquist), and *Trichograptus dilaceratus* Herrmann (identical with *T. crinitus* Törnquist). The last-mentioned species occurs in abundance on a few bedding surfaces in the lower half of the zone.

The frequence of *Didymograptus vacillans* Tullberg culminates in the zone of *D. balticus.* Only one specimen has been encountered just above the upper boundary of this unit. Present in the whole zone, and trespassing into the next younger one, are *Didymograptus minutus* Törnquist (mostly scarce). *Tetragraptus quadribrachiatus* (J. Hall), and *T. amii* Elles & Wood. *Didymograptus suecicus* Tullberg and *Phyllograptus rotundatus* Monsen appear in the upper beds of the zone. In addition, two specimens of *Didymograptus praenuntius* Törnquist have been encountered in the uppermost strata. The three lastmentioned species proceed to the overlying shales with *Phyllograptus densus.*

Undeterminable fragments of *Schizograptus* and (or) *Temnograptus* are fairly frequent in the shales of the zone. From the outcrops at Flagabro Törnquist (1904) records the occurrence of *Schizograptus reticulatus* Nicholson, *S. rotans* Törnquist, and *Temnograptus multiplex* Nicholson.

Caryocaris sp. is common at the base and the top of the zone; otherwise, it is scarce. *Lingulella* spp., *Acrotreta* spp., and *Broeggeria* sp. are by far less frequent than in the underlying units.

The Norwegian shales corresponding to Törnquist's zone of *Didymograptus balticus* were divided by Monsen (1937) into a lower zone of *Didymograptus validus* and an upper zone of *D. balticus.* Characteristic of the lower subdivision are, *inter alia, Didymograptus balticus, D. validus* Törnquist, and *D. holmi.* In addition, multiramous dichograptids, *e. g. Herrmannograptus milesi* (J. Hall), and *Loganograptus kjerulfi* abound in these strata. In the upper zone the frequence of *Didymograptus balticus,* as well as that of *D. filiformis,* culminates.

Other characteristic species are *Didymograptus vacillans* and *Clonograptus herrmanni.*

In the Flagabro core no similar subdivisions are discernible. Probably the Scanian shales with *Didymograptus balticus* are less complete stratigraphically than the corresponding Norwegian strata.

BILLINGEN STAGE

Remarks. — The beginning of the Billingen Age is distinguished by a new transgression. Shales and (or) limestones belonging to the basal part of the stage are found in Skåne, Öland, Östergötland, Västergötland, Närke, Dalarna, the South-Bothnian District, and Jämtland. An index fossil for the lowermost limestone beds is *Megalaspides dalecarlicus* (Holm). The basal shale strata are characterized by the appearance of *Phyllograptus densus* Törnquist and *Didymograptus gracilis* Törnquist. Furthermore, the abundance of *D. minutus* Törnquist is conspicuous. All these species were encountered for the first time at Skattungbyn in Dalarna, and were described by Törnquist (1879, 1890) and by Holm (1882). At Skattungbyn thin limestone beds and lenses with *Megalaspides dalecarlicus* are embedded in shales with *Phyllograptus densus, Didymograptus gracilis,* and *D. minutus.* The occurrence of these species makes possible a correlation of the initial strata of the stage.

The shales of the Billingen Stage contain a well defined graptolite fauna dominated by species of the genus *Phyllograptus. P. densus* and *P. angustifolius* J. Hall are present throughout the shales, while the occurrence of *P. angustifolius elongatus* Bulman is restricted to the upper strata of the stage.

Probably these upper strata were unknown to Törnquist. At Flagabro the lower shales of the stage are well exposed on the southern bank of the rivulet. The upper shales, on the contrary, are hidden by a thick covering of soil.

The fauna characteristic of the upper shales was encountered by Monsen (1937) at some localities in the Oslo Region. She introduced a new zone of *Phyllograptus angustifolius elongatus* succeeding Törnquist's zone of *Phyllograptus densus* in the Lower Didymograptus Shales of Norway.

Strata containing *P. angustifolius elongatus* were found by the present author (Tjernvik, 1956, p. 141) in the Lower Didymograptus Shales at Stora Backor in Västergötland. Following the lead of Monsen he distinguished a Swedish zone of *Phyllograptus angustifolius elongatus.* At Stora Backor this zone is very poorly developed. In the Flagabro core the shales of the unit are much thicker and, in addition, much richer in graptolite species. The distribution of the latter affirms that the Norwegian classification is applicable to the Swedish shales. The two zones of the stage are called in the following:

B 2. Zone of *Phyllograptus densus* and *P. angustifolius elongatus.*
B 1. Zone of *Phyllograptus densus* and *Didymograptus gracilis.*

Some graptolite species common to the two zones are: *Phyllograptus densus, P. angustifolius, Didymograptus praenuntius, Trichograptus bulmani* Monsen, and *Isograptus norvegicus* Monsen. Characteristic of the lower zone are: *Didymograptus gracilis* Törnquist, *D. protoindentus* Monsen, *D. leptograptoides* Monsen, *D. ensjöensis* Monsen, and the abundance of *D. minutus* Törnquist. Representative of the upper unit are: *Phyllograptus angustifolius elongatus, Didymograptus gracilis crassus* Monsen, *D. deflexus scanicus* n. subsp., *Azygograptus ellesi* Monsen, and *Tetragraptus bigsbyi askerensis* Monsen.

B 1. Zone of *Phyllograptus densus* and *Didymograptus gracilis.* — Thickness about 2 m (28.10—30.05 m).

The zone is made up of grey shales, alternately dark- and light-coloured, with seams of almost black shale. The lower strata are, on the whole, darker than the upper ones. A thin limestone bed is present near the top of the unit. Glauconite grains abound at several levels, especially in the lower part of the zone.

The upper boundary of the unit coincides with a surface of sliding, occurring at the 28.10 m level. No doubt, this sliding is due to a fault; in the exposures at Flagabro the zone is more than one metre thicker than in the core.

Nineteen graptolite species or subspecies have been secured from the shales of the unit. *Phyllograptus densus* is the fossil most frequently met with. *P. augustifolius* and *P. rotundatus* Monsen are common in the upper strata of the zone.

Several forms turn up and disappear within the limits of the subdivision. They are: *Didymograptus protoindentus, D. leptograptoides, D. ensjöensis, D. gracilis,* and *Tetragraptus fruticosus campanulatus* Monsen.

Didymograptus minutus abounds on many surfaces of bedding, and proceeds to the lower strata of the overlying zone. Another frequent species is *D. praenuntius. Trichograptus bulmani* and *Isograptus norvegicus* make their appearance in the unit, and trespass into the next younger one. They are accompanied by *Didymograptus suecicus* Tullberg.

Further species obtained are: *Didymograptus vacillans* (at the very base of the zone), *D. nanus* Lapworth/*minutus, Tetragraptus quadribrachiatus, T. amii, T. bigsbyi,* and *Clonograptus* sp.

Lingulella spp. and *Broeggeria* sp. are scarce. A *Caryocaris,* probably conspecific with *C. monodon* (Gurley), is more common.

B 2. Zone of *Phyllograptus densus* and *P. angustifolius elongatus.* — Thickness 3.70 m (24.40—28.10 m).

The shales of the unit resemble those of the underlying zone, and contain likewise a bed of limestone. In the lower part of the subdivision the shales are dark-coloured and rich in glauconite grains. The latter are often accumulated in thin, scattered layers of shale. In the upper beds the grains are scarce or absent.

Nineteen graptolite forms have been encountered in the strata of the unit. *Phyllograptus densus, P. angustifolius,* and the long rhabdosomes of *Phyllograptus angustifolius elongatus* are frequent throughout the subdivision. *P. rotundatus* is less common.

Good index fossils are *Didymograptus gracilis crassus* and *D. deflexus scanicus* n. subsp. The former occurs from the base to the top of the unit; the latter is lacking in the lowermost layers only.

Two other forms characteristic of the zone are *Azygograptus ellesi* and *Tetragraptus bigsbyi askerensis.* As evident from specimens found in the exposures of the locality they proceed to the top of the unit.

Didymograptus minutus and *D. praenuntius* disappear in the lower part of the zone, while *Trichograptus bulmani* and *Isograptus norvegicus* still persist in the top strata.

Other species obtained are: *Didymograptus suecicus, D. kreklingensis* Monsen, *Tetragraptus bigsbyi, T. fruticosus* (J. Hall) subsp.?, *T.* cf. *harti* T. S. Hall (27.80 m), *Loganograptus kiaeri* Monsen (24.55—24.60 m), and *Clonograptus* cf. *rigidus* (J. Hall) (26.10—26.15 m).

At the 24.40 m level the shale strata are cut off by an oblique fault, revealed by a conspicuous surface of sliding. It dips about 45°. Above this surface a repetition takes place of the shale sequence. The overlying beds contain *Didymograptus balticus, D. geometricus,* and other graptolite species representative of the zone of *Didymograptus balticus.* These strata have been excluded from the core section in text-fig. 2.

At the Flagabro rivulet the thickness of the zone is about 4 metres.

Preliminary notes on the lacking top strata of the shales

The uppermost strata of the Lower Didymograptus Shales are not represented in the core. They have been exposed through diggings carried out on the southern bank of the Flagabro rivulet, about 70 metres south-east of the site of the drilling. The excavations extend from the Limbata Limestone to the top beds of the zone of *Phyllograptus densus* and *P. angustifolius elongatus.* The upper boundary of this zone (and of the Billingen Stage) is distinguished by a conspicuous layer of glauconite sand, a couple of centimetres thick.

The overlying shales, which have a thickness of about 5 metres, are greenish grey, with seams of dark shale. They contain a characteristic graptolite fauna very different from that of the Billingen Stage. The Australian species *Didymograptus distinctus* Harris & Thomas is found all through the strata. It is associated with *D. slemmestadi* Monsen, *Azygograptus suecicus* Moberg, and a peculiar species suggestive of an *Orthograptus.* Two stratigraphical units are discernible:

C 2. Zone of *Didymograptus distinctus* and *Isograptus gibberulus.*
C 1. Zone of *Didymograptus distinctus* and *D.* »*patulus* Törnquist».

In the lower unit *Didymograptus "patulus* Törnquist" is abundant. It is accompanied by an early form of *D. hirundo* Salter.

These species are scarce in the the shales of the upper unit. This subdivision is, on the other hand, characterized by the occurrence of *Maeandrograptus schmalenseei* Moberg, *Pterograptus* n. sp., and — at higher levels — *Isograptus gibberulus* Moberg.

The shales are overlain by Arenigian Limbata Limestone.

Description of subspecies

Didymograptus deflexus scanicus n. subsp.

Text-fig. 3.

NAME. — Latin *scanicus* = from the province of Scania.

HOLOTYPE (here selected). — Almost complete rhabdosome, numbered LO 4011 T, and kept in the museum of the Palaeontological Institution of Lund.

TYPE STRATUM AND TYPE LOCALITY. — Shales belonging to the zone of *Phyllograptus densus* and *P. angustifolius elongatus,* Flagabro, Scania.

DIAGNOSIS. — The subspecies differs from *Didymograptus deflexus* Elles & Wood in the distal portions of its stipes diverging at a far less open angle; furthermore, in a somewhat less number of thecae in a given length.

DESCRIPTION. — As in the typical form described by Elles and Wood (1901—1918, p. 35, pl. II, figs. 12 a—c) the stipes are at origin narrow, and widen fairly rapidly to a breadth of about 1 mm. They diverge from the sicula to form an inverted V, but expand afterwards to include a more open angle. In *scanicus* this angle is less obtuse than in the specimens pictured by Elles and Wood. In the holotype of the subspecies it is about 110°, in another specimen about 120°.

The stipes are slender, being at the aperture of the first theca in the holotype about 0.5 mm wide; at the 17th theca 0.9 mm. The thecae number 12 to 13 in 10 mm (in the typical form, 14 thecae). They are inclined to the axis at an angle of about 30°. They are about three times as long as wide, and the outer margins free to one half their length. The apertural margin is slightly concave. The sicula is 2 mm long and slender (in text-fig. 3 it is broken). In the holotype the stipes are about 15 mm long.

OCCURRENCE. — Zone of *Phyllograptus densus* and *P. angustifolius elongatus* (Arenigian). — Skåne (Scania): Flagabro.

Summary

The stratigraphical subdivisions distinguished in the Lower Didymograptus Shales at Flagabro and their contents of graptolite and trilobite species are as follows:

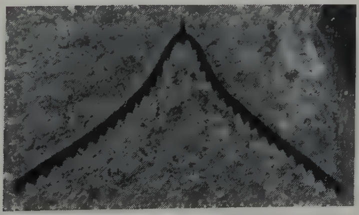


Fig. 3. Holotype of *Didymograptus deflexus scanicus* n. subsp. Photograph retouched by the author. — 2×.

Lower Didymograptus Shales (Arenigian)

C. UNNAMED STAGE

2. Zone of *Didymograptus distinctus* and *Isograptus gibberulus:*
Isograptus gibberulus Moberg, *Maeandrograptus schmalenseei* Moberg, *Pterograptus* sp., *Didymograptus distinctus* Harris & Thomas, *D. slemmestadi* Monsen, *Azygograptus suecicus* Moberg, *Trochograptus diffusus* Holm, etc.

1. Zone of *Didymograptus distinctus* and *D. "patulus* Törnquist":
Didymograptus "patulus Törnquist", *D. hirundo* Salter (narrow form), *D. distinctus, D. slemmestadi, Azygograptus suecicus, Trochograptus diffusus,* etc.

B. BILLINGEN STAGE

2. Zone of *Phyllograptus densus* and *P. angustifolius elongatus.*
Phyllograptus densus Törnquist, *P. angustifolius elongatus* Bulman, *P. angustifolius* J. Hall, *P. rotundatus* Monsen, *Didymograptus gracilis crassus* Monsen, *D. deflexus scanicus* n. subsp., *D. minutus* Törnquist, *D. praenuntius* Törnquist, *D. suecicus* Tullberg, *D. kreklingensis* Monsen, *Isograptus norvegicus* Monsen, *Tetragraptus bigsbyi* (J. Hall), *T. bigsbyi askerensis* Monsen, *T.* cf. *harti* T. S. Hall, *T. fruticosus* (J. Hall) subsp.?, *Loganograptus kiaeri* Monsen, *Clonograptus* cf. *rigidus* (J. Hall), *Trichograptus bulmani* Monsen, and *Azygograptus ellesi* Monsen.

1. Zone of *Phyllograptus densus* and *Didymograptus gracilis.*
Phyllograptus densus, P. angustifolius, P. rotundatus, Didymograptus gracilis Törnquist, *D. leptograptoides* Monsen, *D. protoindentus* Monsen, *D. minutus, D. nanus* Lapworth/*minutus, D. vacillans* Tullberg, *D. ensjöensis* Monsen, *D. praenuntius, D. suecicus, Isograptus norvegicus, Tetragraptus quadribrachiatus* (J. Hall), *T. amii* Elles & Wood, *T. bigsbyi, T. fruticosus campanulatus* Monsen, *Trichograptus bulmani,* and *Clonograptus* sp.

A. HUNNEBERG STAGE

3. Zone of *Didymograptus balticus.*
Didymograptus balticus Tullberg, *D. balticus vicinatus* Monsen, *D. vacillans, D. vacillans attenuatus* Monsen, *D. minutus, D. holmi* Törnquist, *D. constrictus* (J. Hall), *D. flexilis* Monsen, *D. suecicus, D. praenuntius, D. filiformis* Tullberg, *D.* cf. *pusillus* Tullberg, *D. geometricus* Törnquist, *Tetragraptus quadribrachiatus, T. amii, T. bigsbyi, T. bigsbyi divergens* Monsen, *T.* aff. *astericus* Monsen, *Dichograptus octobrachiatus* (J. Hall), *Loganograptus kjerulfi* Herrmann, *Herrmannograptus regularis* Törnquist, *Clonograptus herrmanni* Monsen, *Trichograptus dilaceratus* Herrmann, and *Phyllograptus rotundatus.* In addition, Törnquist has collected *Schizograptus reticulatus* Nicholson, *S. rotans* Törnquist, and *Temnograptus multiplex* Nicholson.

At the lower boundary of the zone some trilobite species have been encountered. They are: *Plesiomegalaspis planilimbata* (Angelin), *Symphysurus angu-*

status Sars & Boeck, *Cyclopyge gallica* Tjernvik, and *Pliomerops actinurus* (Dalman).

2. Zone of *Tetragraptus phyllograptoides.*

Tetragraptus phyllograptoides Törnquist. In addition, Törnquist has collected *Didymograptus undulatus* Törnquist and *D. constrictus.*

Trilobites: *Plesiomegalaspis planilimbata, Niobella bohlini* Tjernvik, *Niobe* cf. *emarginula* Angelin, *Symphysurus angustatus,* and *Geragnostus wimani* Tjernvik.

References

ELLES, G. L. and WOOD, E. M., 1901—1918: Monograph of British Graptolites. Palaeont. Soc. London.

HOLM, G., 1882: Ueber einige Trilobiten aus dem Phyllograptusschiefer Dalekarliens. — Bih. K. Svenska Vet.-Akad. Handl. Bd 6. N:o 9. Stockholm.

LINDSTRÖM, M., 1957: Two Ordovician conodont faunas with zonal graptolites. — GFF 79, pp. 161—178. Stockholm.

MONSEN, A., 1937: Die Graptolithenfauna im Unteren Didymograptusschiefer (Phyllograptusschiefer) Norwegens. — Norsk Geol. Tidskr. Bd 16, pp. 57—263. Oslo.

TJERNVIK, T. E., 1956: On the Early Ordovician of Sweden. Stratigraphy and fauna. — Bull. Geol. Inst. Upsala. Vol. XXXVI, pp. 107—284. Uppsala.

— 1958: The Tremadocian beds at Flagabro in South—eastern Scania (Sweden). — GFF 80, pp. 259—276. Stockholm.

TÖRNQUIST, S. L., 1875: Berättelse om en geologisk resa genom Skånes och Östergötlands paleozoiska trakter, sommaren 1875. — K. Vet.-Akad. Förh. N:o 10, pp. 43—70. Stockholm.

— 1879: Några iakttagelser öfver Dalarnes graptolitskiffrar. GFF 4. Stockholm.

— 1890: Undersökningar öfver Siljansområdets graptoliter. — Lunds Univ. Årsskr. Bd 26. Lund.

— 1901 and 1904: Researches into the graptolites of the lower zones of the Scanian and Vestrogothian Phyllo-Tetragraptus beds. — Lunds Univ. Årsskr. Bd 37. Afd. 2. N:r 5, and Bd 40. Afd. 2. N:r 2. Lund.

A Preliminary Report on a Boring through Middle Ordovician Strata in Western Scania (Sweden)

By

RAGNAR NILSSON

Abstract: A drilling core from Koängen, situated in the Fågelsång district, Scania, representing a section through the uppermost strata of the subzone of *Climacograptus haddingi,* the zone of *Nemagraptus gracilis,* and the lowermost part of the zone of *Diplograptus multidens,* is described. The portion of the core so far treated demonstrates the zone of *N. gracilis* of the Fågelsång district to be overlain by shales the lower part of which contains a graptolite fauna belonging to the zone of *D. multidens.* It also shows that these layers, following immediately above the zone of *N. gracilis,* can not be identical with those of the zone of *Dicranograptus clingani* in south-eastern Scania, and further that the zone of *Diplograptus molestus* ought not to be maintained any longer in the Fågelsång district.

Our knowledge of the sequence of the Middle Dicellograptus shale in the Fågelsång district is imperfect. In order to establish in particular the nature of the layers following next above the zone of *Nemagraptus gracilis,* a boring was carried out at the Koängen farm in the spring of 1954 with the aid of a grant from Statens Naturvetenskapliga Forskningsråd (Swedish Natural Science Research Council).

The analysis of the core is being undertaken by a team, and the writer has been entrusted with the examination of the layers underlying the Sularp shale and of the graptolites of the entire core. As the completion of the work is likely to take some time, it is considered desirable to publish the main facts hitherto established. To Professor G. Regnéll, Head of the Paleontological Institute of the University of Lund, I am very indebted for permission to work at this institute. I also wish to acknowledge my obligation to Dr M. Lindström, Lund, who has facilitated the investigation in every way, to Mr S. Bergström for determination of some specimens of conodonts, and to Dr V. Jaanusson and Dr I. Strachan for their help in obtaining graptolite material from Great Britain for comparison.

The drilling was carried out by the Svenska Diamantbergborrnings Aktiebolaget (Swedish Diamond Drilling Co, Stockholm) between Feb. 29th and March 19th, 1954, at the Koängen farm, 200 m south-east of the farmhouse, about 4.7 km east of Lund. Permission to carry out the boring on the grounds of Koängen was kindly given by the owner, Mr Eric Andersson.

The boring reached a depth of 70.30 m below the surface, and pierced Lower Dicellograptus shales with the uppermost part of the subzone of *Climacograptus* *haddingi,* and the whole zone of *N. gracilis;* Middle Dicellograptus shales with Sularp shale; Upper Dicellograptus shales and Quaternary deposits. The diameter of the core is 70 mm.

The Cambro-Silurian strata around Fågelsång have been subjected to considerable displacement after the deposition and consolidation of the sediments. This circumstance also characterizes the rocks of the core. Cracks or fissures, a fraction of one to five mm wide and filled with calite or pyrite, thus penetrate the shales as well as the limestone vertically or at an angle, their frequency changing with the depth. In general, the bedding surfaces are smooth, and undulating bedding planes have been observed as an exception only. The dip of the beds varies from 10° to 16°. Slip surfaces are not infrequent, and are usually accompanied by only slight dipping.

Description of the Sequence

LOWER DICELLOGRAPTUS SHALES

Zone of *Glyptograptus teretiusculus*
Subz. of *Climacograptus haddingi* (/70.30/—67.35 m).

Dark grey, almost black, very finely grained, sometimes calcareous shale and mudstone. Lens-shaped, black, finely crystalline limestone, up to 5 mm in thickness, occurs at various depths in the upper part of the subzone. Finely crystalline pyrite is common. The mineral is found in the form of scattered minute crystals or small aggregates, occasionally with small crystals of calcite. Pyrite is observed also as veins or in tubular, straight or winding form with a length up to 3 cm and a diameter of 1 to 4 mm. The pyrite often penetrates the shales vertically or obliquely. Fillings of the cavities of brachiopods or graptolites by pyrite are uncommon. Flakes of biotite up to about 1 mm in diameter occur infrequently, in general only a few flakes on a bedding plane. Between 67.73 and 67.51 m there are four beds of metabentonite. In the lower part of the core one or two nodules of phosphorite have been found, and between 67.495 and 67.35 m a band of phosphorite occurs. The rock is dark grey, somewhat brownish, very finely grained, hard and very rich in pyrite in the form of microcrystals which are frequently concentrated in irregular, smaller or larger concretions or continuous layers. Pyrite is predominant in the upper half of the band. Small crystals of calcite or aggregates of the mineral occur in abundance, and also associated pyrite and calcite are common. The phosphorite is penetrated by numerous narrow cracks filled with pyrite or calcite, or both. Scattered flakes of biotite have been observed.

In the phosphorite band fossils are scarce, and occur mostly in the form of microfossils, although traces of indeterminable, pyritic graptolites have been seen. The microfauna includes *Rhabdochitina* and other chitinozoans, and conodonts, e. g. *Acontiodus* sp.?, *Prionodus* sp., and *Pygodus anserinus* Lamont & Lindström. Scattered ostracods also occur. The zonal position of the phosphorite band has been to some degree uncertain. Hadding (1913, pp. 14—17) was inclined to refer the band to the subzone of *C. haddingi,* while Hede (1951,

p. 66) considered it probable that the band belonged to the zone of *N. gracilis.* For the determination of the stratigraphic position of the band the occurrence of *Pygodus anserinus* is significant. This conodont is rather common in the upper part of the subzone of *C. haddingi* in Scania and corresponding strata of Great Britain (Lamont & Lindström 1957), and until now has not been found in higher horizons. Since the vertical range of the species does not seem to exceed the subzone of *C. haddingi,* which underlies the band of phosphorite, the band possibly represents the termination of the sedimentation of this zone. The zone is rich in fossils, the species encountered in the shale being: *Desmograptus* cf. *tullbergi* Hadding?, *Azygograptus mobergi* Hadding?, *Janograptus laxatus* Tullberg, *Cryptograptus tricornis* (Carruthers), *C. tricornis schäferi* Lapworth, *Glossograptus* cf. *armatus* Nicholson, *G. scanicus* Hadding, *Nemagraptus subtilis* Hadding, *Dicellograptus intortus* Lapworth, *D. vagus* Hadding, *Climacograptus haddingi* Glimberg, *C. scharenbergi* Lapworth, *C.* cf. *caudatus* Hadding (non Lapworth), *Diplograptus propinquus* Hadding?, *Amplexograptus perexcavatus* (Lapworth), *Glyptograptus teretiusculus* (Hisinger), *Gymnograptus linnarssoni* (Moberg), *Rhabdochitina* sp. and other chitinozoans, sponge spicules, scolecodonts, ostracods, phyllocarids, *Obolus deltoideus* Hadding, *O. ornatus* Hadding, *O. sularpensis* Hadding, *Leptobolus elatus* (Hadding), *L. fimbriatus* (Hadding), *Hisingerella nana* (Hadding), *Paterula bohemica* Barrande?, *Lingula dicellograptorum* Hadding, and *Acontiodus* sp.?, *Pygodus anserinus* Lamont & Lindström, and other conodonts.

Zone of *Nemagraptus gracilis* (67.35—60.76 m = 6.59 m).

This part of the core consists of dark grey to black, very fine-grained shale and mudstone. Pyrite is relatively scarce and occurs mostly as separate very minute crystals which are occasionally concentrated into more or less small irregular aggregates. Small flakes of biotite are common, especially in metabentonite, 15, usually thin, beds of which have been observed. Occasionally layers, at the most 4 cm thick, of dark grey or black, hard, mostly finely crystalline limestone, often with quite numerous minute crystals of pyrite, occur, especially in the uppermost part of the core. Fossils are scarce in the limestone. Where adjacent to the limestone the shale is often more or less calcareous. The zone is very fossiliferous, with the graptolites predominant. The following graptolites have been found: *Corynoides curtus* Ruedemann, *C. curtus pristinus* Ruedemann, *C. incurvus* Hadding, *Glossograptus* cf. *armatus* Nicholson, *Glossograptus* sp., *Leptograptus* aff. *grandis* Lapworth, *L.* cf. *flaccidus* Hall, *L. validus* cf. *incisus* Elles & Wood, *Leptograptus* sp., *Nemagraptus gracilis* (Hall), *N. gracilis remotus* Elles & Wood, *Dicellograptus divaricatus salopiensis* Elles & Wood, *D. sextans exilis* Elles & Wood, *Dicranograptus ramosus* (J. Hall), *Climacograptus antiquus* Lapworth, *C. bicornis* (J. Hall), *C. bicornis tridentatus* Lapworth, *C. brevis* Elles & Wood, *C. scharenbergi* Lapworth, *Diplograptus molestus* Thorslund, *D. notabilis* Hadding, *D. toernquisti* Hadding, *Amplexograptus perexcavatus* (Lapworth), *Glyptograptus teretiusculus* (Hisinger), *G. euglyphus* Lapworth, *Orthograptus apiculatus* (Elles & Wood)?, *Hallograptus mucronatus* (J. Hall), *Lasiograptus costatus* Lapworth, *Retiograptus geinit-*

zianus J. Hall, *Lasiograptus spinatus* Hadding. Other fossils are: *Conochitina* sp., *Rhabdochitina* sp., — a form similar to *Conochitina campanulaeformis* Eisenack is abundant in the lower part of the zone, while the genus *Rhabdochitina* makes its appearance in the zone at 65.83 m — sponge spiculae *(Hexactinellida)*, *Obolus* cf. *celsus* Hadding, *O.* spp., *Leptobolus elatus* (Hadding), *L.? kiaeri* (Hadding), *Paterula bohemica* Barrande, *P.* sp., *Lingula dicellograptorum pulla* Hadding, *Hisingerella nitens* (Hisinger), *Onniella* sp. *Sericoidea* sp., *Orthoceras* sp., scolecodonts, ostracods, phyllocarids, conodonts, undetermined microfossils.

MIDDLE DICELLOGRAPTUS SHALE

Zone of *Diplograptus multidens* (60.76—57.99 m +).

The shale and mudstone in this part of the core are similar to the beds in the *gracilis* zone. There occur in addition — especially in the upper part — numerous layers of a dark grey to black, finely crystalline hard limestone and thin beds of metabentonite, where cracks are particularly common. In the fauna graptolites and chitinozoans predominate, brachiopods occupying a more modest place and scolecodonts, ostracods, conodonts, and other organisms usually only scantily represented. There are no indications of a bottom fauna. Richly fossiliferous layers with numerous bedding planes entirely covered with graptolites alternate with layers poor in fossils. In the limestone fossils are rare, and the metabentonites are in general unfossiliferous. The graptolites in the zone of *D. multidens* are partly the same as in the zone of *N. gracilis*. They are: *Corynoides curtus* Lapworth, *C. curtus pristinus* Ruedemann, *C. incurvus* Hadding, *Nemagraptus gracilis* (Hall), *N. gracilis remotus* Elles & Wood, *Dicellograptus divaricatus salopiensis* Elles & Wood, *Climacograptus antiquus* Lapworth, *C. bicornis* (J. Hall), *C. brevis* Elles & Wood, *C. scharenbergi* Lapworth, *Diplograptus molestus* Thorslund, *Glyptograptus euglyphus* Lapworth, *G. teretiusculus* (Hisinger), *Hallograptus mucronatus* (J. Hall), and *Lasiograptus costatus* Lapworth. In all 15 species or varieties are represented. In addition to these the following graptolites appear here for the first time: *Corynoides tricornis* Ruedemann, *C.* cf. *gracilis* Hopkinson, *Dicellograptus* cf. *patulosus* Lapworth, *D.* cf. *pumilus* Lapworth, *Climacograptus antiquus lineatus* Elles & Wood, *C. modestus* Ruedemann, *C. peltifer* Lapworth, *C. wilsoni* Lapworth?, *Diplograptus multidens* (Elles & Wood), *D. multidens* cf. *compactus* (Elles & Wood), *Amplexograptus arctus* Elles & Wood, *Glyptograptus teretiusculus* cf. *siccatus* Elles & Wood, *Orthograptus calcaratus* (Lapworth), *O. calcaratus* cf. *acutus* Lapworth, *O. calcaratus* cf. *incisus* Lapworth, *O. truncatus* cf. *intermedius* Elles & Wood, *O. vulgatus* Lapworth, *Hallograptus bimucronatus* (Nicholson), *Lasiograptus harknessi* (Nicholson). In the remaining part of the fauna chitinozoans, including the genera *Conochitina* and *Rhabdochitina* are predominant. Other fossils are: Sponge spicules (Hexactinellida), *Obolus* spp., *Leptobolus elatus* (Hadding), *L.? kiaeri* (Hadding), *Paterula* sp., *Hisingerella nitens* (Hisinger), *Onniella* sp., *Sericoidea* cf. *restricta*

(Hadding), *Sericoidea* sp., *"Orthoceras"* sp., scolecodonts, ostracods, phyllocarids, *Acontiodus* sp., *Paracordylodus* sp., *Roundya* sp.? *Panderodus* sp., cf. *Prioniodus* sp., and other conodonts, and *Thamnograptus* sp.?

Stratigraphical Remarks

Moberg (1896, pp. 15—16) stated that the layers above the zone of *Nemagraptus gracilis* in western Scania were identical with the zone of *Dicranograptus clingani* in south-eastern Scania, in spite of the fact that they were characterized by *Climacograptus rugosus* Tullberg (= *Diplograptus molestus* Thorslund) instead by *D. clingani*. He designated them as the zone of *Climacograptus rugosus* Tbg., but referred to the beds in a later publication (1907, p. 80) as the "zone of *Dicranograptus clingani* Carr. or *Climacograptus rugosus* Tullb.". Olin (1906, p. 79) found specimens of *D. clingani* together with *C. rugosus,* and Törnquist (1913, p. 421) considered that the zone of *C. rugosus* ought to be identical with the zone of *D. clingani*. In 1915 Hadding stated that the Middle Dicellograptus shale could be divided into the following zones (in descending order):

Zone of *Climacograptus styloideus*
Dicranograptus clingani
Amplexograptus vasae
Climacograptus rugosus

In the Fågelsång district the zone of *C. styloideus* is absent as far as we can tell at present and, according to Moberg (1896, p. 15) the zone of *D. molestus* has been considered to be equivalent to the zone of *D. clingani* in south-eastern Scania, though characterized by *D. molestus* instead of *D. clingani*. Since *D. molestus* is one of the predominant graptolites of the zone of *Nemagraptus gracilis* in the Fågelsång district (Hede 1951, p. 67), its use as an index fossil for a zone named by it is unsuitable.

Lithologically the portion of the core examined so far is fairly uniform, and the sedimentation seems to have proceeded continuously at least from the deposition of the zone of *Nemagraptus gracilis*. The only lithologically conspicuous stratigraphic break is marked by the phosphorite band between the zones of *Climacograptus haddingi* and *Nemagraptus gracilis,* provided that the thin layer of metabentonite overlying the *N. gracilis* zone should not be regarded as a sign of a break. In any case this layer constitutes a defined faunistic limit with new graptolite species appearing in the shale overlying the metabentonite.

Orthograptus calcaratus and in even larger numbers *O. vulgatus* make an appearance here, and characterize the fauna in the core between 60.76 and 58.20 m. These species, either separately or both together with other graptolites such as *Corynoides* cf. *curtus pristinus, Dicellograptus divaricatus salopiensis, Climacograptus antiquus, C. modestus, Diplograptus molestus, Glyptograptus* cf. *euglyphus, Lasiograptus costatus,* and *Hallograptus bimucronatus* often cover the bedding planes.

From a stratigraphic point of view the orthograptids are of considerable importance. *O. calcaratus,* which in Sweden is known from the zone of *Dicranograptus clingani* in south-eastern Scania, appears in Great Britain in the zone of *Climacograptus wilsoni,* and reaches its greatest abundance in the zone of *Dicranograptus clingani.* According to Pocock etc. (Dean 1958, p. 227) *O. vulgatus* is common in the zone of *Diplograptus multidens* in Shropshire, its vertical range extending through this zone and even into the zones of *C. wilsoni* and *D. clingani.* Of interest also is *O. truncatus* cf. *intermedius,* recorded in a few specimens, which is common in Great Britain in the zones of *D. multidens* and *C. wilsoni,* and which occurs likewise in the zone of *D. clingani.* Other stratigraphically important diplograptids are *D. multidens* and *D. multidens* cf. *compactus.* In Great Britain the former is confined to the zones of *D. multidens* and *C. wilsoni,* while the latter is encountered also in the zone of *D. clingani.* Furthermore, *O. apiculatus* and *C. peltifer*[1] are reported in Great Britain only from the zone of *D. multidens,* and *Lasiograptus harknessi* from the zone of *D. multidens, C. wilsoni* and *D. clingani.*

This evidence seems to suffice for assigning the graptolite assemblage in the core immediately above the *N. gracilis* zone to the zone of *Diplograptus multidens.* Examination of the vertical range of certain graptolites ascending from the *gracilis* zone lends further support to this opinion. Thus *D. divaricatus salopiensis, C.* cf. *brevis,* and *Hallograptus bimucronatus* do not go beyond the zone of *D. multidens,* and *C. antiquus lineatus, Glyptograptus teretiusculus, G. euglyphus,* and *Lasiograptus costatus* do not exceed the zone of *C. wilsoni.* In the core the species mentioned decrease in number in upward direction, and, with exception of *D. divaricatus salopiensis,* have not been observed from 58.33 to 57.99 m.

Somewhat remarkable is the simultaneous occurrence of older and younger graptolite species which here appear with 15 species or varieties ranging upwards from the *gracilis* zone, and 19 species appear for the first time. This mixed fauna together with the great "burst" of *Orthograpti* constitutes in reality an analogy to similar conditions which, according to Elles (1937), characterize the transition beds (zone of *Diplograptus multidens*) in Great Britain, and which have been recorded also from the beds at Sularp (Nilsson 1953).

The above observations seem to confirm the opinion (Nilsson, l. c.) that the layers following immediately above the zone of *Nemagraptus gracilis* in the Fågelsång district could not be identical with the zone of *Dicranograptus clingani* in south-eastern Scania, and that with regard to the vertical range of *Amplexograptus rugosus* these layers ought not to be assigned to a zone of *Amplexograptus rugosus* (= *Diplograptus molestus*). The layers immediately above the zone of *Nemagraptus gracilis* must instead be included in the *Diplograptus multidens* zone corresponding to that zone in Wales in Great Britain.

---

[1] According to Elles (1937, p. 486) rare finds of *C. peltifer* have been made in the zone of *N. gracilis* in South Wales.

The upper limit of the *multidens* zone has not yet been defined, but the overlying Sularp shale (Lindström 1953) should probably be assigned to the zone of *D. multidens* also.

Some Notes on the Metabentonite

It has been considered advisable not to burden the foregoing account with further mention of a series of thin layers, probably altered volcanic ashes — in this paper called metabentonite — which have been observed in the core. The metabentonite is light grey to dark grey, sometimes with a slight greenish tint, and owing to its colour and soft nature contrasts sharply with, and is clearly defined from the dark, relatively hard mudstone. The metabentonic rock, which rapidly breaks up and disintegrates in water, often contains numerous regularly distributed, very minute crystals and grains of pyrite, exceptionally concentrated into thin lamellae. Flakes of biotite up to 1 mm in diameter are common, occurring sometimes in large numbers. The layer below the metabentonite mostly consists of dark grey to black limestone or calcareous hard mudstone. Where present, the limestone is crystalline, and is underlain by hard mudstone with numerous small crystals or aggregates of calcite, which progressively increase in numbers in an upwards direction. Occasionally also the layer above the metabentonite consists of a similar limestone which seems to have been formed by concentration of small crystals of calcite.

In the uppermost part of the zone of *Climacograptus haddingi* 4 beds of metabentonite are found, in the zone of *Nemagraptus gracilis* there are 15, and in the lower part of the zone of *Diplograptus multidens* 17 layers of this rock. The beds are very thin — none exceeding 3.5 cm and half less than 0.5 cm — and no correspondence has been observed to the bentonite beds in the *gracilis* zone of Bornholm which in places are nearly 110 cm thick (Gry 1948, p. 374). In this connection it is worth mentioning that about 40 bentonite beds occur in the still unexamined upper part of the core which ought to be correlated with other corresponding occurrences in Scandinavia. Thus, the beds between 40.82 and 41.76 m probably correspond to those at Mossen and Kullatorp in Västergötland with thicknesses of 180 and 170 cm resp. (Thorslund 1948) and to the thick layer at Billingen in the same district (Byström 1957). Also the bentonite bed XII at Sinsen in Norway (Hagemann & Spjeldnaes 1955) should be attributed to the same period of volcanic activity.

The opinion that the bentonite beds in the Middle Ordovician of Sweden decrease in thickness towards the south, or, more exactly, towards Scania-Bornholm, seems to be based on the fact that the bentonite beds hitherto known from these peripheric parts of the area, within which the volcanic material is distributed, seem to be relatively thin. However, there is reason to suppose that tectonic disturbances which are more frequent in the southern area of Fennoscandia than in the Cambro-Silurian region of Västergötland may have in some other way reduced the original thickness of the beds in question. Similar conditions within the Oslo district in Norway are due to the Caledonian folding (Hagemann & Spjeldnaes 1955, p. 33).

Distribution of the Metabentonite Beds in the Core between 57.99 and 70.30 m.

Depth below Surface	Thickness of Bed	Depth below Surface	Thickness of Bed
Z.o. *Diplograptus multidens.*		Z.o. *Nemagraptus gracilis.*	
57.990—58.000 m	0.1 cm	60.760—60.770 m	0.7 cm
58.050—58.051	0.1	61.010—61.055	< 0.1
58.142—	< 0.1	61.110—61.125	1.5
58.198—58.200	0.2	61.145—61.150	0.5
58.285—58.287	0.2	61.530—61.540	1.0
58.351—58.355	0.4	61.705—61.740	3.5
58.642—58.643	0.1	63.345—63.370	2.5
58.680—58.705	2.5	63.600—63.602	0.2
58.845—58.900	1.5	63.875—63.877	0.2
58.705—58.970	0.1	64.310—64.320	0.1
59.170—59.174	0.4	65.800—65.805	0.5
59.310—59.335	2.5	66.345—66.350	0.5
59.528—59.530	0.2	66.680—66.840	0.1
59.599—59.600	0.1	67.050—67.060	< 0.1
60.000—60.010	1.0	67.125—67.127	0.2
60.210—60.225	1.5		
60.379—60.380	0.1	Z.o. *Climacograptus haddingi.*	
		67.510—67.512	0.2
		67.600—67.620	0.2
		67.685—67.690	0.5
		67.725—67.730	0.1

References

GFF = Geologiska Föreningens i Stockholm Förhandlingar.
LUÅ = Lunds Universitets Årsskrift.

Byström, A. M., 1957: The clay minerals in the Ordovician bentonite beds in Billingen, Southwest Sweden. — GFF 79.

Dean, W. T., 1958: The Faunal Succession in the Caradoc Series of South Shropshire. — Bull. British Museum (Natural History) Geology. Vol. 3. No. 6.

Elles, G. L. & Wood, E. M. R., 1901—1918: A monograph of British graptolites. Parts I—VII. — Paleontogr. Soc. London.

— 1937. The Classification of the Ordovician Rocks. — Geol. Mag. Vol. LXXIV.

Gry, H., 1948: Bentoniten i Bornholms ordovicium. — Medd. Dansk Geol. for. 11.

Hadding, A., 1915: Der mittlere Dicellograptus-Schiefer auf Bornholm. — LUÅ. N. F. Afd. 2. Bd 11. No. 4.

Hagemann, F. and Spjeldnæs, N., 1955: The Middle Ordovician of the Oslo Region, Norway 6. Notes on bentonites (K-bentonites) from the Oslo-Asker district. — Norsk Geol. Tidsskr. Bd 35.

Hede, J. E., 1951: Boring through Middle Ordovician-Upper Cambrian strata in the Fågelsång District, Scania (Sweden). — LUÅ. N. F. Avd. 2. Bd 46. No. 7.

Lindström, M., 1953: On the lower Chasmops beds in the Fågelsång District (Scania). — GFF 75.

Lamont, A. & Lindström, M., 1957. Arenigian and Llandeilian Cherts identified in the Southern Uplands of Scotland by means of Conodonts etc. — Trans. Edin. Geol. Soc. Vol. 17. Part 1. Edinburgh.

Moberg, J. C. 1896: Geologisk vägvisare inom Fogelsångstrakten. — Medd. Lunds Geol. Fältklubb. No. 2.

— 1907. Ett par bidrag till kännedomen om Skånes dicellograptusskiffer. — GFF 29.

Nilsson, R., 1953: Några iakttagelser rörande undre och mellersta dicellograptusskifffern i västra Skåne. Abstract: Some observations concerning the Lower and Middle Dicellograptus shale in western Scania. — GFF 75.

OLIN, E., 1906: Om de chasmopskalken och trinuscleusskiffern motsvarande bildningarne i Skåne. — LUÅ. N. F. Afd. 2. Bd 2. No. 3.

RUEDEMANN, R., 1947: Graptolites of North America. — Geol. Soc. America. Mem. 19.

THORSLUND, P., 1948: The Chasmops series of the Kullatorp core. (In Waern, B., Thorslund, P., & Henningsmoen, G., Deep boring through Ordovician and Silurian strata at Kinnekulle, Vestergötland) — Bull. Geol. Inst. Upsala. Vol. 32.

TÖRNQUIST, S. L., 1913: Några anmärkningar om indelningar inom Sveriges kambro-silur. — GFF 35.

Enrichment of Organic Matter from Clays

By

G. Assarsson and V. Grundulis

Geological Survey, Ghemical Laboratory
Stockholm 50

Sedimentary formations precipitated under marine or lacustrine conditions generally contain organic matter in varying amounts and of varying origin. The organic substance often plays an essential role in the properties of the sediments and even small variations in organic matter may be important in geological and geotechnical problems.

The organic matter in minerogenic sediments can be thought as behaving in the following way. The common hydrophilic clay minerals (mica, kaolinite, montmorillonite) and other minerals (quartz, feldspar) occur in textures characterized as "honeycomb", "network", "cardhouse", "haystack", by different authors; a summary is given by Rosenqvist (1). The consolidation of the sediments is thought to take place by the linking of hydroxyl bridges or other ions between the hydrated clay particles. In most Quaternary clays the minerals have been mixed with a hydrophilic organic substance, chiefly consisting of phyto-detritus ("gyttja") originating from plants of various kinds. One may imagine the organic detritus adhering to the polarized elements of the minerals and in this way stabilizing the texture mentioned above. The chemical properties and the amount of the organic detritus should therefore be of considerable importance in distinguishing the physical behaviour of the clays.

In most cases Quaternary minerogenic clays contain rather low amounts of organic matter, making thorough investigations of its properties difficult. For example, determination of the composition of the organic matter is complicated by the presence of hydrophilic minerals. For this reason the amount of organic matter is generally calculated approximately by multiplying the carbon content by a factor. A better knowledge of the properties of organic matter in soils can be gained if this component is enriched in a convenient manner.

While working with flotation of organic matter in Cambrian sediments of sapropelitic character, the present writers, stimulated by discussions with dr J. Eklund, decided to try similar methods with Quaternary sediments. It would be most advantageous if such a procedure could achieve a 10-fold concentration or more. The method for the flotation of organic matter, which

Table 1. Enrichment of organic material from clays by flotation.

Analyses % per substance dried at 100.°

No.	Content of water % in orginal material	Starting material			Sinking material				Floating material I				Floating material II			
		C	H	Ash	C	H	Ash	Factor of enrichment	C	H	Ash	Factor of enrichment	C	H	Ash	Factor of enrichment
1	46	0.75	0.42	96.5	0.62	0.34	97.2	0.83	2.50	0.79	93.3	3.3	—	—	—	—
2	47	1.18	0.39	95.8	0.91	0.30	96.6	0.77	2.98	0.70	93.3	2.5	7.85	1.59	80.8	6.7
3	45	1.38	0.40	95.9	1.04	0.35	96.6	0.75	7.72	1.53	81.2	5.6	—	—	—	—
4	47	0.68	0.58	95.8	0.58	0.30	96.3	0.85	4.63	1.00	89.3	6.8	—	—	—	—
5	43	1.27	0.42	94.7	0.94	0.27	96.6	0.74	4.72	0.93	89.1	3.7	9.14	1.77	79.2	7.4
6	32	1.30	0.50	94.5	1.16	0.37	96.5	0.90	4.30	1.16	88.8	3.3	—	—	—	—
7	35	1.49	0.43	95.0	1.05	0.35	97.2	0.70	4.37	0.78	90.6	2.9	15.65	2.54	65.3	10.5

had been successfully used with Cambrian shales, was therefore applied after some minor changes to Quaternary sediments. The procedure is described below.

We always start with samples having natural water content. There is no essential objection to the use of slightly air-dried samples provided that they can be dispersed in water without difficulty. It should be kept in mind, however, that some properties of the organic components can change considerably during air-drying.

The sample, corresponding to about 10 g air-dried clay, is dispersed in 0.01 N ammonia water to form a thick slurry. This slurry is transferred into a mechanical mixer together with ammonia water and 25 ml ligroin (b.p. 60—85°), mixed for 5 minutes and gradually diluted up to about one liter. The mixture is than transferred to four or five glass cylinders of about one liter each. After the cylinders are filled nearly to the brim with ammonia water, the suspension is mixed thoroughly and left to settle for about 24 hrs. The ligroin gradually floats up to the surface together with most of the organic matter. The collected fractions are washed carefully by centrifuging with acetone and dried in an air bath at 60°. The flotation procedure is repeated two or three times or as long as additional organic matter is gained.

About 15 samples of organic detritus-bearing clay material from a vertical section through a predominantly marine clay were treated according to the above method; some results are given in Table I. Six of the samples of Table I were treated only once; in some cases the samples could be divided into more than two fractions by centrifugation (samples 2 and 5). One sample was treated twice (sample 7). In all preparations from the clay section an enrichment was achieved, the lowest and highest factors of enrichment being about 2.5—7 for the samples treated once; for the twice-treated sample the factor was 10. From the experiments it also seems probable that a separation of the organic detritus itself into fractions with different properties could be made by suitable arrangements. It is also possible to gain an advantageous enrichment of certain phyto-fragments for other purposes (pollen analysis, age dating).

The calculation of the composition of the phyto-detritus based on the enrichment above, and the investigation of other properties will not be reported here. The present report is intended only to underline the feasibility of the procedure described above. The investigation will be continued.

Literature

1. Rosenqvist, 1958: G.F.F., 80, 433.

On the Relations between Kinetometamorphism and Metasomatism in Granitization

Some Examples from the Archean of Eastern Sweden

By

SVEN GAVELIN

Mineralogical Institute, University of Stockholm

Abstract

Some problems concerning the relationship between the kinetometamorphism and metasomatic transformation during granitization and formation of veined gneisses are discussed. The discussion is based mainly on certain field examples in the Stockholm and Västervik areas of Central and Southern Sweden to be visited during excursions connected with the 21st International Geological Congress.

The mechanical behaviour of various rock types are considered in the light of their structural patterns, the purpose being to establish the relative plasticity/rigidity of the rocks during deformation. Reaction zones surrounding inclusions of metabasite or metaarenite in pegmatitic veined gneisses indicate a mineral formation which involves an exchange of chemical elements between the gneiss mass and the inclusions. The reactions took place in the presence of a mobile phase which supplied some water and potassium to parts of the rock sequence. Whereas the mineral compositions of the inclusions indicate their mineral development to have occurred under amphibolite facies conditions, the reaction zones represent epidote-amphibolite facies.

Pure quartzites are found to behave plastically when metabasite fractures. Bodily flow of those quartzites that border on amphibolite is sometimes found to be connected with an intense replacement of the quartzites by plagioclase. The process leads to the formation of pegmatitic or granitic rocks possessing high mobility.

It is suggested that the migration of chemical elements and diffusion connected with granitization and pegmatitization can be profoundly facilitated through kinetometamorphism under certain conditions and that kinetometamorphism therefore must be considered an important factor in interpretations of granitization and pegmatitization phenomena.

Introduction

The present paper is intended to give a brief account of certain granite-gneiss problems which will be met with during excursions connected with the 21st International Geological Congress. The examples to be considered are located in the Stockholm and Västervik areas on the Swedish east coast. The investigations in the areas mentioned are not yet complete, and it is therefore not possible to give a comprehensive presentation of all the geological features which may have a bearing on the problems outlined. However, some of the results already gained seem to offer interesting and more general aspects on granite-gneiss problems and it may therefore be justified to present a preliminary report.

The material to be presented refers mainly to certain structural patterns and their interpretation. At present the discussions must be focussed mainly on field data. The two areas mentioned are perfectly suited for an approach of this kind, since there are excellent outcrops, which often make it possible to record structural features in great detail.

I am well aware that the structural patterns discussed are not unique, and any geologist who has worked in similar gneiss and granite regions will be familiar with most of them. The figures on the following pages are produced merely to exemplify a structural development which may be taken to characterize many granite-gneiss areas. They are intended to serve as a basis for a discussion of certain ideas of the author concerning genetic problems of granites and gneisses and which are founded not only on the observations described in the present paper but also on many years of personal experience from field work in various Fennoscandian Archean regions.

Comments on the Geology of the Stockholm and Västervik Areas

In the present connection the geology of the Stockholm and Västervik areas will not be comprehensively treated. A brief survey of the rocks and the geologic evolution is presented in the guide to Excursions A28—C23 of the 21st International Geological Congress (Gavelin—Lundegårdh, 1960).

Veined gneisses are common in both areas. Their structural patterns are indicated by the figures in Magnusson (1938; the Stockholm area) and Du Rietz (1947; the Västervik area). Transitions between gneisses and granitic rocks are frequently met with, but clearly late- or post-kinematic granites and pegmatites also occur, which penetrate and brecciate the gneisses. Feldspathization leading to augen-gneisses is fairly common; it often develops selectively in stratified or otherwise heterogeneous rock sequences. The gneisses south of Stockholm generally contain almandite, cordierite, and sillimanite (in addition to the chief constituents quartz, plagioclase, microcline, biotite, and some muscovite); in the Västervik gneisses sillimanite is an abundant constituent.

The gneisses to be discussed in the present paper are assumed to have been mainly formed from sediments, but basic volcanic and plutonic rocks were also present in the rock sequence affected by metamorphism. The metabasites — now appearing as amphibolites — may originally have represented basic tuffites, lavas, dikes or sills, or diorites and gabbros. In the Stockholm area early-orogenic tonalites or granodiorites have sometimes been taken up in the gneiss metamorphism. The sediments in the Stockholm area are believed to represent a sequence of wide lateral extension and corresponding to the Larsbo sediments in Central Sweden (Bergslagen), described by Hjelmqvist (1935). On the whole they can be characterized as members of the graywacke suite in the sense of Pettijohn (1957). Poorly sorted beds of argillaceous and arenaceous beds frequently alternate. The development of the gneisses south of Stockholm makes it probable that arenites were subordinate as compared with the argillaceous graywackes. In the Västervik area, on the other hand, the arenaceous members of the sedimentary column are much more frequent, and fairly pure quartzites (orthoquartzites) often dominate quantitatively. This is an important difference between the two areas, especially in respect to the mechanical behaviour of the rock sequences during tectonism.

In both areas the gneiss formation is intimately connected with strong tectonism which has created highly varying and complicated patterns. It is believed that this tectonism was preceded by a phase of gentle folding. The movements connected with regional thermal and metasomatic metamorphism (gneiss formation and granitization) are characterized by intense shearing. In the opinion of the author this phase of deformation caused the regional arc-structure characteristic of the areas south of Stockholm.

Physical Properties of the Rocks in the Stockholm and Västervik Areas

At present no reliable quantitative data are available concerning the physical properties of the rocks in the two areas mentioned which would make it possible to give accurate values of the amounts of stress and strain necessary to cause fracturing, flow, etc. On the other hand, the structural patterns as revealed in outcrops frequently give a good idea of the relative flow/rupture

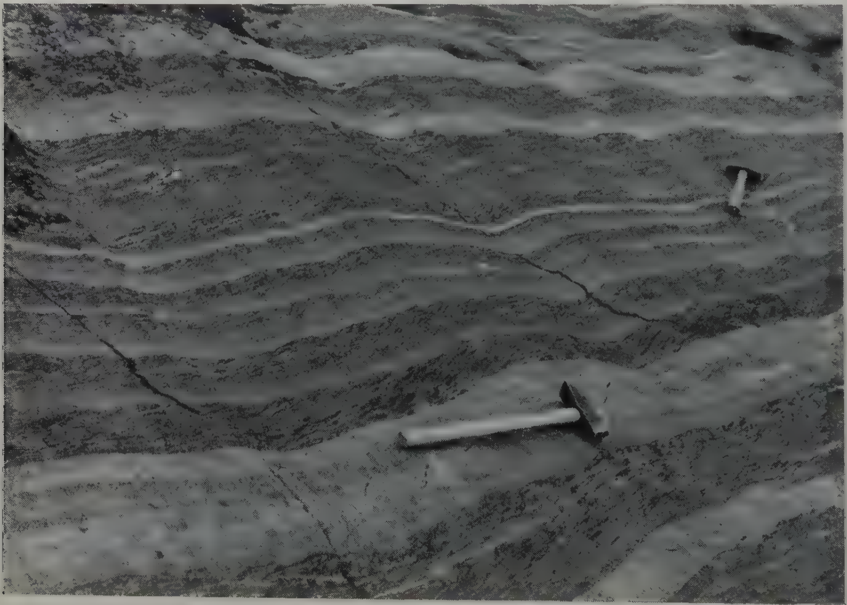


Photo: Th. Lundqvist

Fig. 1. Originally argillaceous and arenaceous interbeds in metamorphic graywacke sediments. Graded bedding is still discernible. Utö, southeastern shore (the Stockholm area).

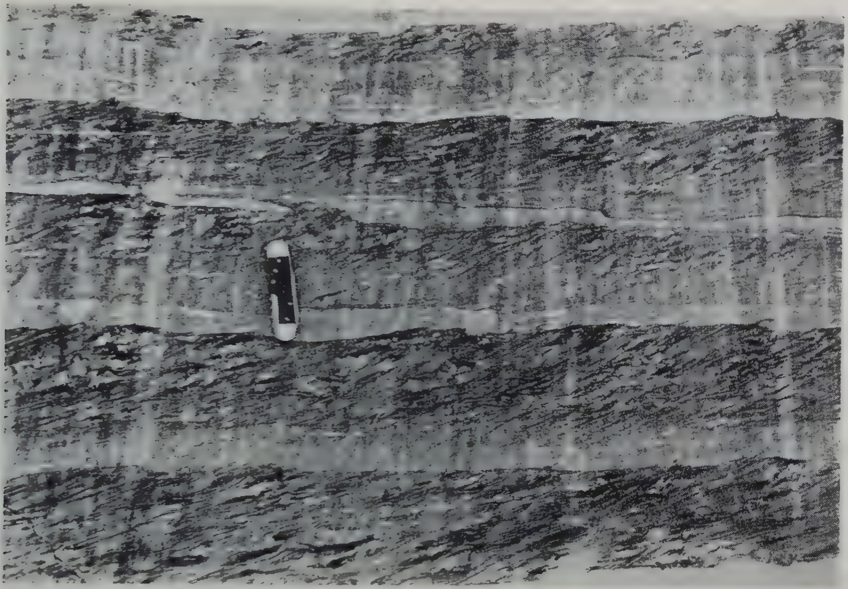


Photo: Th. Lundqvist

Fig. 2. Bedded graywacke sediments displaying transverse schistosity in the argillaceous layers. Utö, southeastern shore (the Stockholm area).

ability. The following members of the rock sequences in the Stockholm and Västervik areas will be considered:

1. Originally arenaceous sediments, in the Västervik area often developed as pure quartzites. 2. Originally argillaceous sediments. 3. Veined gneisses, *i.e.* gneisses with considerable amounts of pegmatitic or granitic matter, but where original sedimentary features are indicated as relict bands or as diffuse bands or schlieren of micaceous gneiss. 4. Metabasites. 5. Homogeneous, individualized fine-grained granite and pegmatite.

Firstly areas outside the gneiss areas proper will be considered. From the regional experience of the tectonic development in the areas mentioned it is postulated that the structural patterns exemplified by figures 1—8 below were formed approximately during the same phase of tectonism as caused the complicated gneiss patterns in adjacent areas. This does not mean that all movements were exactly synchronous within and outside the gneiss areas. The field data show, that the deformation often occurred in several steps. Within each area, however, all the structures exemplified and discussed below are believed to have been formed in close connection with that kind of thermal and metasomatic metamorphism which produces gneisses and granitic rocks.

The relations between the arenaceous and argillaceous members of the sediments under the pertaining stress conditions are exemplified by figs. 1—4, representing the sediments of the Stockholm area (Utö), and by figs. 5—8, representing the Västervik area. Normal bedding is illustrated by Figs. 1, 2, and 5. In fig. 2 the difference in physical properties between the various beds is shown

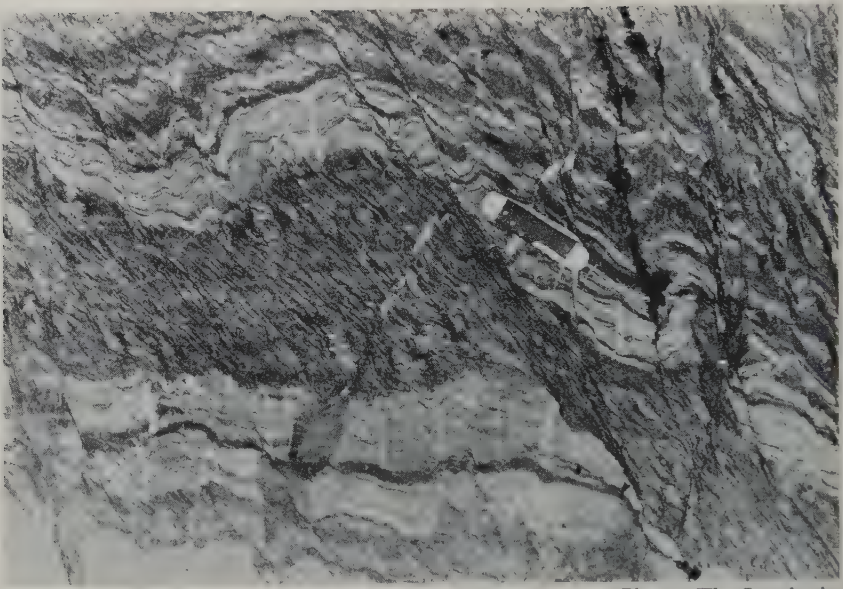


Photo: Th. Lundqvist

Fig. 3. Folded bedded graywacke sediments displaying transverse schistosity in the argillaceous beds. Utö, southeastern shore (the Stockholm area).

by the occurrence of cleavage and schistosity in the metaargillites, orientated obliquely towards the primary bedding. The movements in the rock mass has in this case evidently been restricted to small intergranular glidings in the beds of poor competence. The metaargillites were very mobile and when stress causes folding the competent metaarenites react in part by fracturing, whereas the metaargillites react by flow (figs. 3 and 4). Exactly the same kind of evolution is demonstrated by figs. 6—8. Figs. 6 and 7 are from the same locality and clearly show, how the metaarenite beds can only be plastically folded to a certain degree; thereafter they fracture and appear as irregular, deformed blocks in the metaargillite. If particular disharmonic stress conditions are realized, turbulent flow may be initiated which results in plastic folding of the S planes, formed during an earlier phase of the deformation (fig. 8).

In the gneiss areas a difference between poorly competent and highly competent rock sections is still more obvious. It is a common experience in both the Stockholm and Västervik areas that the development of veined structure in an interbedded arenaceous-argillaceous rock sequence has begun in the argillaceous beds. Now, since the argillaceous beds were originally poorly sorted they generally contained sandy material and there may have been gradations between the various chief constituents of the sedimentary sequence. However, where clearly separate beds of original sandstone occurred in association with shaly sediments the former are often still identifiable, sometimes as irregular inclusions in the veined gneiss mass. Thus, in the Västervik area narrow belts of gneiss of the same appearance as the main rock in fig. 12 are found in mas-

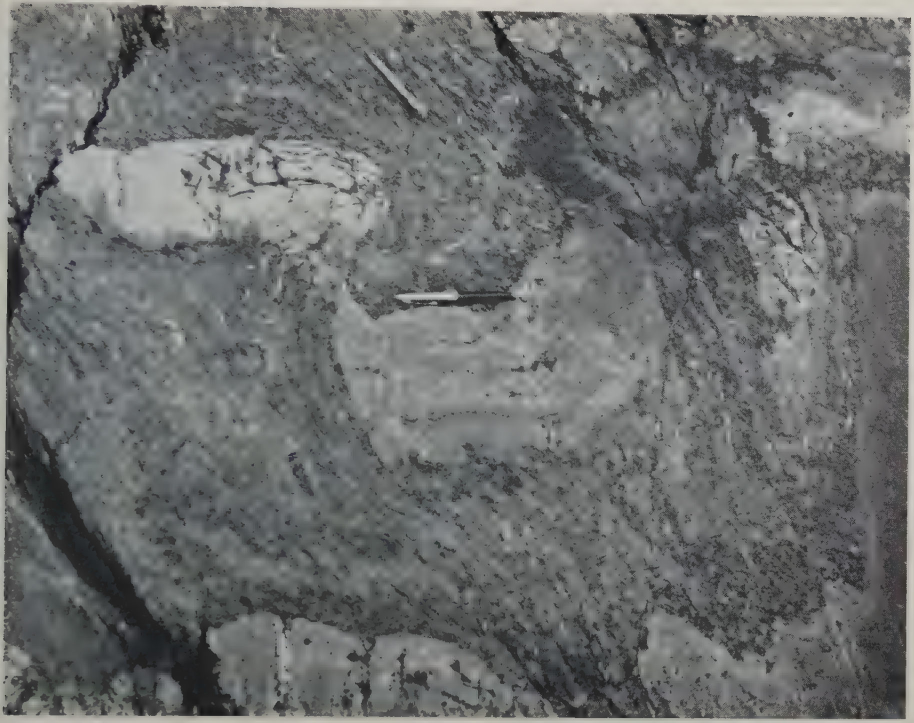


Photo: G. Folcker

Fig. 4. Fractured pieces of competent metaarenite beds in incompetent metaargillite.Utö, southeastern shore (the Stockholm area).

sive pure quartzite, which shows no other sign of metamorphism than intense recrystallization. In cases where the gneiss dominates, the same kind of quartzites appear as lenses or irregularly shaped blocks in the veined gneiss and are generally arranged in rows which indicate the original bedding. It was mentioned above, that there is good reason to believe that the veined gneisses in the Stockholm area are derived from mainly argillaceous sediments. Sometimes, however, remnants of metaarenites can be observed (fig. 11), the structural pattern then definitely showing them to have been more competent than the gneiss portion.

The metabasites behaved in the same way as the arenites. Figs. 9 and 10 are from outcrops close to that in fig. 11 and represent very typical patterns in an area where movements were to great extent turbulent. Fig. 9 represents the deformation pattern of a rock mass, where several layers, dikes, or sills of basic rocks apparently have existed prior to the metamorphism of the neighbouring fine-grained graywackes. The occurrence of flow lines in the gneiss makes it sometimes possible to trace the original connection between the various metabasite pieces. In fig. 10 a connection between the metabasite blocks is no longer discernible; these metabasites apparently occurred in thicker beds or intrusions before the beginning of the movements. Fig. 12 from the Västervik

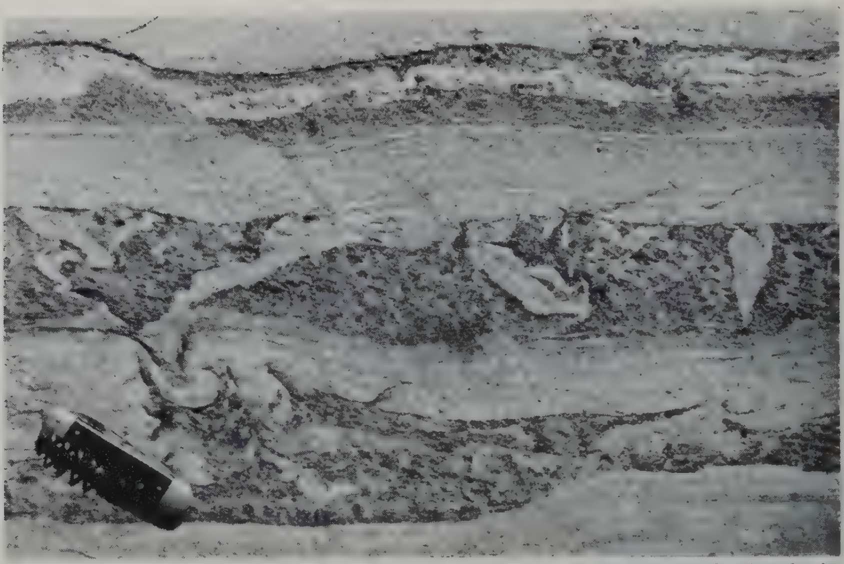


Photo: Th. Lundqvist

Fig. 5. Originally arenaceous and argillaceous sediments. Small. sand-filled cracks in the interbedding argillaceous beds. L. Äppelholmen (the Västervik area).

area shows how metabasite dikes, probably due to boudinage, were broken and how the pieces have drifted apart.

The above examples show clearly that the development of the veined gneiss was connected with intense movements, that the gneiss mass was highly mobile at a certain stage of its evolution and reacted by plastic flow, whereas the pure metaarenites and metabasites reacted by fracturing.

The physical differences between the veined rock portion on one hand and metaarenites and metabasites on the other were too great to permit conclusions on the mutual relations between the two last-mentioned rock types when subjected to a common strong stress. The Stockholm sediments contain little pure arenite material and can therefore give no information in this respect. The Västervik area is characterized by large masses of frequently very pure quartzites (with 90—99 % quartz) which are sometimes cut by abundant metabasite dikes or sills. Some very interesting and illuminative examples on the behavior of these rocks when subjected to strong stress will be given below.

On walking along the southeastern shore of Grönö, S. W. of Spårösund, one first crosses a several hundred meters broad belt of very pure, coarse, massive quartzite. Some narrow beds of veined gneiss about a meter wide and striking W.N.W.—E.S.E. are first met with. Towards the north the veined gneiss increases in importance and at the southern end of Spårösund only narrow beds of quartzite are found in the gneiss. (Fig. 12 is from this northern part of the section.) The sequence apparently represents a transition from pure quartz sandstones into a series where thin layers of feldspathic sandstone alternate with argillaceous graywacke. Both the pure quartzites and the fine-bedded

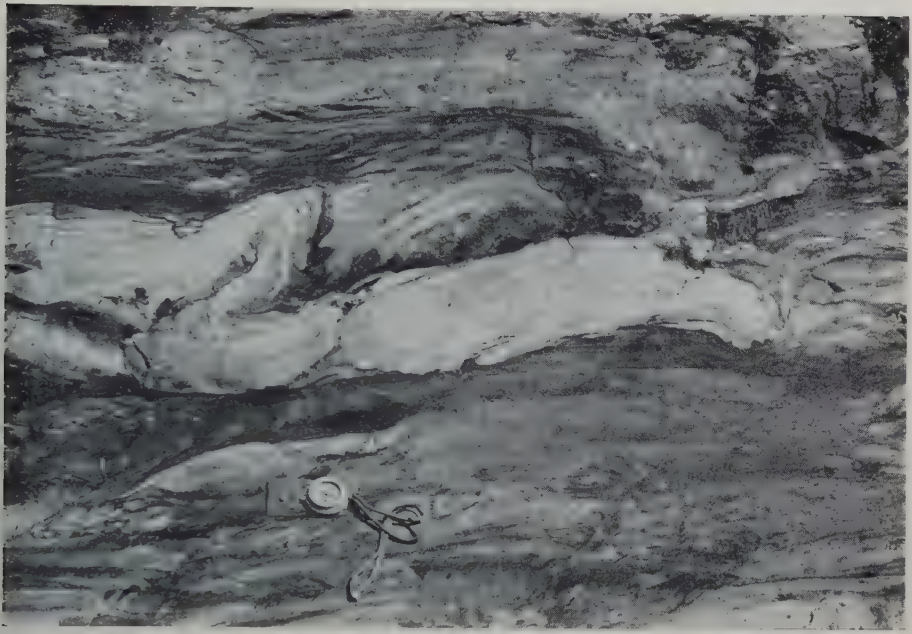


Photo: S. Gavelin

Fig. 6. Folded interbedded graywacke sediments. The competent metaarenite layers in part fractured. Almviksnäs, western shore (the Västervik area).

sediments contained metabasites. The entire rock sequence has been affected by intense shear parallel to the bedding. The behavior of the metabasites in the bedded sediments which were transformed to veined gneisses is described above. The metabasites occurring in pure quartzites are mostly parallel to the main orientation of the bedding and consequently also to the direction of shear. These metabasites have sometimes been submitted to boudinage and then appear as lenses, which form rows that indicate the original direction of the dikes. Consequently the metabasite was more competent than the quartzite. The general impression given by the structural patterns is, however, that the difference in physical properties was not so great between the quartzite and the metabasite as between the veined gneiss and the metabasite. Nevertheless the quartzite must have yielded by plastic flow when the metabasite failed by fracture. The ability of the quartzite to flow is illustrated by fig. 13 from the quartzite portion of the rock section described above. In this case a metabasite cuts the direction of shear at an angle of around 30°. Parallel to the direction of shear the metabasite is transected by narrow bands (1—2 cm wide) of quartzite (see fig. 13). The mechanism by which this structure originated seems obvious: Strong shearing stress caused a set of shear fractures to develop in the metabasite. Under the prevailing pressure conditions the quartzite was sufficiently plastic to be squeezed into the dike fractures; a certain tensional stress component acting in the direction of the dike may also have contributed to the flow.

Principally similar relations have been observed in several places within the

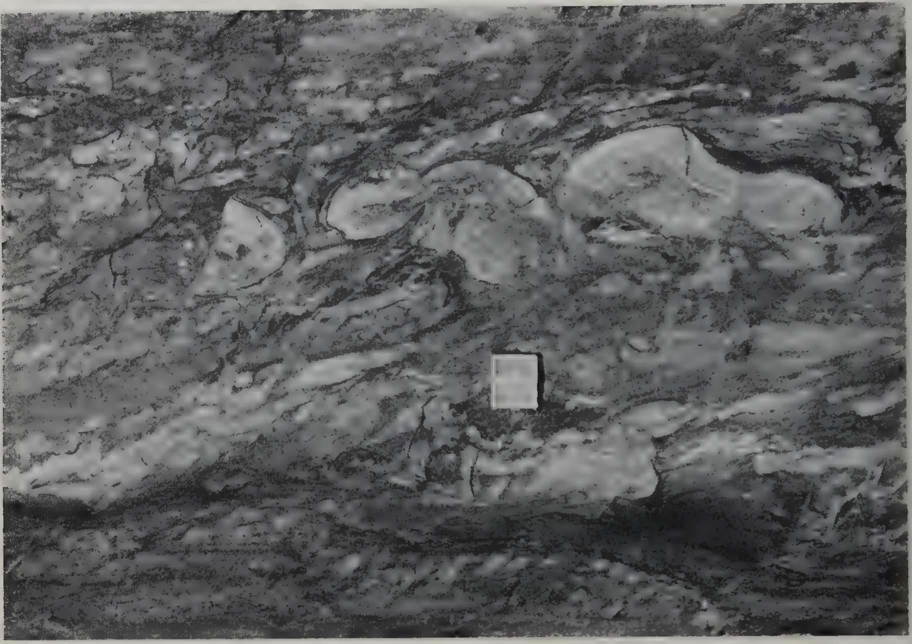


Photo: S. Gavelin

Fig. 7. Deformed pieces of competent metaarenite beds in incompetent metaargillates as a result of strong shear in bedded graywacke sediments. Almviksnäs, western shore (the Västervik area).

Västervik area. Fig. 14 is a sketch of a thicker metabasite intrusion which contains inclusions of quartzite. Quartzite was squeezed into cracks in the metabasite, but in this case a certain flow in parts of the metabasite also seems to have occurred, apparently as a late stage of deformation, which caused schistosity in the metabasite and splitting of the quartzite veins. Two samples of quartzite from this locality (of xenoliths and veins respectively) were examined by petrofabric analyses of the quartz orientation. Preferred orientation was found in both samples but the petrofabric diagrams are definitely different. It is obvious, however, that a comprehensive discussion of the relations between quartz orientation and the movements requires further analytic data from more material. In the present preliminary report it may only be stated that petrofabric diagrams indicate the boundary faces between metabasite and quartzite to have influenced the quartz orientation in the quartzites.

Fig. 15 is another example of quartzite squeezed into a metabasite dike from the southern part of the area examined. In this case the thin quartzite "vein" is seen to attain a pegmatitic development.

Figs. 16 and 17 show similar relationships between metabasite and quartzite at a fourth locality. In this case broken pieces of metabasite have sometimes drifted further apart than in the above examples represented by figs. 13—15; the metabasite pieces were also rotated somewhat in the "plastic" quartzite. Those parts of the quartzite which must have been particularly mobile are also

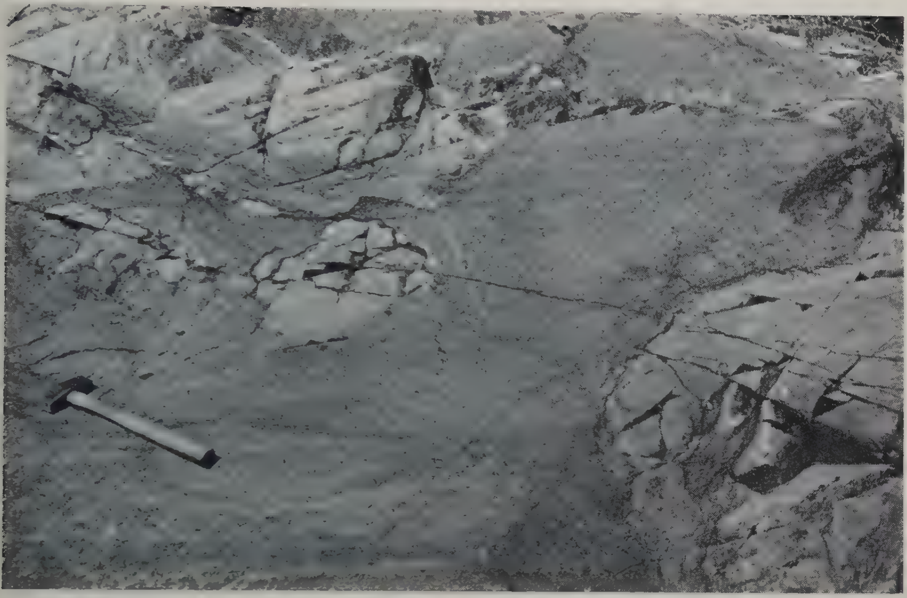


Photo: S. Gavelin

Fig. 8. Fractured pieces of pure quartzite in incompetent metaargillites. Skjortö, western shore (the Västervik area).

feldspathized in this example and megascopically attain even a pegmatitic appearance.

In Figs. 18—20 quite other patterns between metabasite and siliceous sediments are shown. Fig. 18 is from a zone some hundred meters wide, characterized by intense shear. Deformation has completely obliterated the original distribution between various rocks, but it is evident that quartzite, arenaceous bedded graywackes, and abundant metabasites were present prior to the deformation. Very irregular mixtures of schistose metabasite and quartzite, generally appearing as veins or schlieren, were formed. The quartzitic veins frequently grade into a coarser feldspar-bearing rock of granitic or pegmatitic appearance (as demonstrated in fig. 19). Micaceous gneisses, probably derived from the graywacke sediments, occur (fig. 18, gray belt in the center, under the compass) and seem to have possessed a somewhat higher mobility than the metabasite-quartzite mass.

Fig. 19 demonstrates a pattern which is very common where heavy masses of metadiorite or metagabbro occur in quartzites. Such metabasites are generally penetrated by a network of gray granitic or pegmatitic veins. Where quartzite occurs as xenoliths, transitions into the granitic or pegmatitic veins have sometimes been observed.

Fig. 20 demonstrates a more uncommon pattern. Metabasite and quartzite have been deformed in a manner that indicates that they reacted with approximately the same degree of folding competence. This would at first seem to be contradictory to the examples demonstrated by figs. 13—17. However,

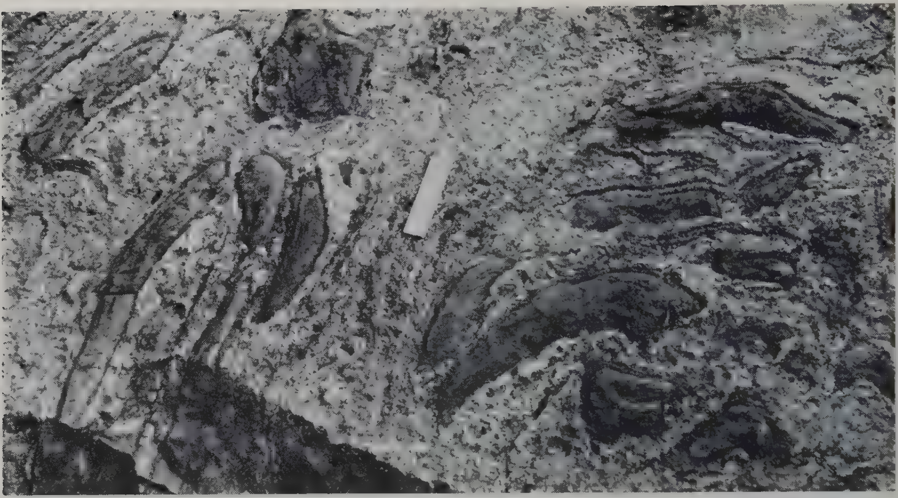


Photo: J. Lundqvist

Fig. 9. Garnetiferous veined gneiss with abundant fragments of amphibolite, displaying reaction zones with the gneiss. Hammarbybacken, Johanneshov (the Stockholm area).

in considering the physical properties of a sufficiently large amount of rock, which includes both quartzite and metabasite, it is obvious that conditions were different in the cases exemplified by figs. 13—17 and that demonstrated by fig. 20. In the former cases metabasite is very subordinate as compared with quartzite. In the latter case metabasite and quartzite apparently formed sets of alternating parallel sheets prior to the deformation. Consequently the rock mass as a whole was definitely anisotropic as regards mechanical strength, the boundaries between quartzite and metabasite probably representing planes of maximum weakness. Both quartzite and metabasite can react by plastic folding to a certain extent. It is a well-known fact that if an interbedded rock sequence is folded the amplitudes of the separate folds decrease as the width of the individual beds decrease and also that the resulting fold pattern is dependent both on the competence of the various beds and on their mutual distribution within the deformed rock sequence. For a mechanical interpretation of this reference may be made to de Sitter (1956, p. 189—190) and Goguel (1952, p. 185—186). From such deductions it can be concluded that the difference in folding competence between metabasites and quartzites of the Västervik area was too small to bring about a clearly disharmonic deformation when the two components occur as alternating sheets with a width of only a few decimeters.

From the examples presented above the following conclusions may be drawn concerning the relative physical properties of quartzites and metabasites during their mechanical deformation: Where metabasites occur as quantitatively subordinate constituents in pure quartzites and deformation is not restricted to certain clearly delimited shear zones in the rock mass, quartzite is definitely more plastic than metabasite (figs. 13—17). Where both quartzite and metabasite are abundant and occur in a restricted shear zone, the stress may bring

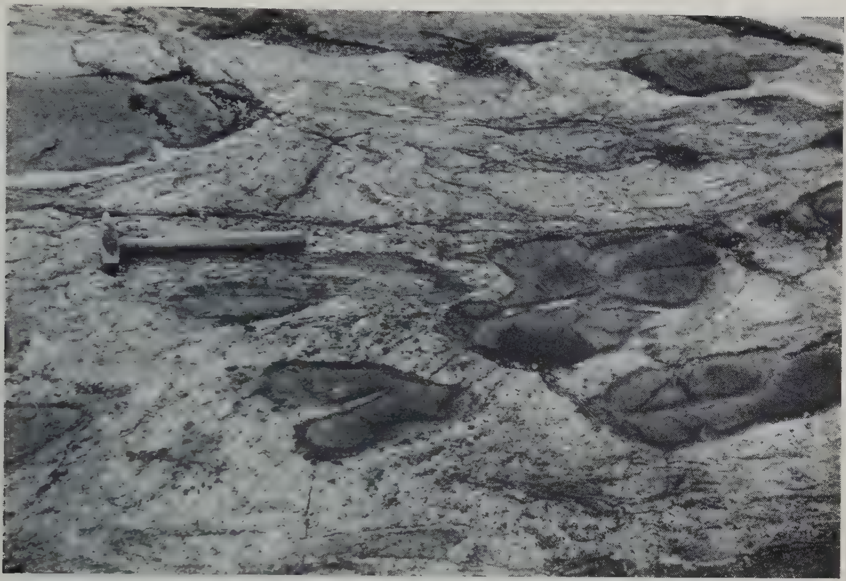


Photo: J. Lundqvist

Fig. 10. Veined gneiss with inclusions of amphibolite. Flow structures are visible in the gneiss. The metabasite fragments are surrounded by biotite-rich reaction zones. Nynäsvägen, Johanneshov (the Stockholm area).

about a certain schistosity and flow also in the metabasites in the last stage of deformation (fig. 18). Where quartzite and metabasite occur as alternating narrow sheets in similar proportions, deformation may develop as drag-folding without discernible difference in the folding competence between the various components (fig. 20).

In the previous chapter it was mentioned that fine-grained granites are common constituents in both the Stockholm and the Västervik areas. Some examples will be discussed below to demonstrate certain features of the structural behavior of these granites at their emplacement. The physical properties of the matter from which the granites crystallized, irrespective of its consistency (if magma or some other plastic matter), can be considered on the basis of its relations to adjacent rocks, as was done above in treating metabasites, quartzites, metaargillites, or gneisses.

Homogeneous granites frequently occur as distinct dikes which clearly cut flow folds of gneisses and which sometimes also contain angular fragments of adjacent rocks. The structural pattern gives in many instances clear evidence of their emplacement by bodily movements of the granitic matter. Where granites are somewhat heterogeneous, for instance due to the occurrence of incompletely incorporated and homogenized gneiss material, biotite-banding parallel to the contacts may indicate the direction of flow. Petrofabric analyses have shown that preferred orientation of biotite does not occur in such rocks (Loberg, 1959), and the movements must therefore be classified as precrystalline and the granite emplacement as postkinematic with regard to the move-

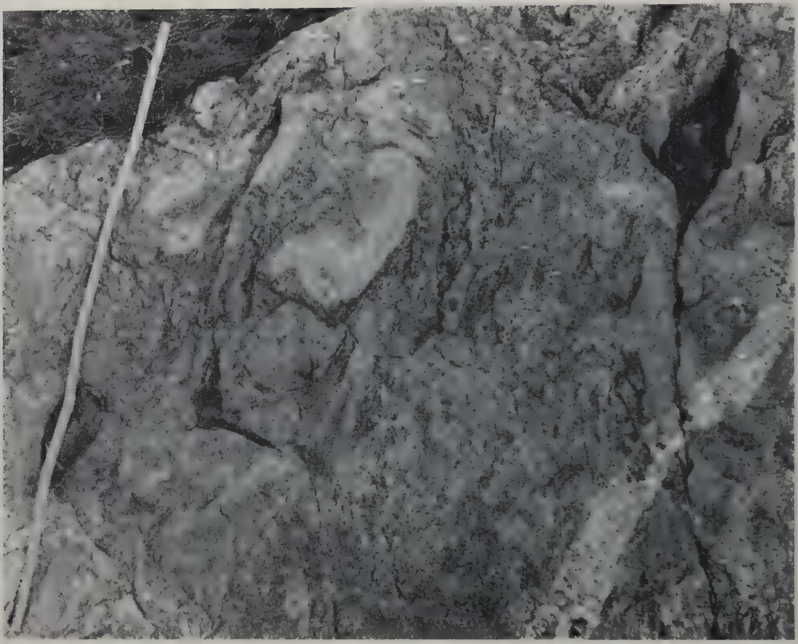


Photo: J. Lundqvist

Fig. 11. Deformed pieces of metaarenite (white) in veined gneiss. Nynäsvägen, Johanneshov (the Stockholm area).

ments in the metasediments. On the other hand, granitic rocks with approximately the same mineral composition, grain-size, and texture as the clearly postkinematic granites also exist, which have been caught up in the last movements of the gneiss folding, in for instance the southern and western parts of the Stockholm area.

The structural patterns thus supply clear evidence of the greater ability of granitic matter to flow over that of the adjacent wall rocks in the emplacement stage of evolution. Since the plastic flow of the veined gneiss rocks in the main represents an earlier stage of deformation it is not possible to compare directly the flow properties of the granitic matter with those of the veined gneiss mass during its stage of maximum mobility. Nevertheless the field data give the general impression that the former was at least slightly more plastic than the latter. A certain idea of the relative mobility of the rocks may be obtained when homogeneous granite contains inclusions of wall rocks.

In many outcrops, where granite brecciates the wall rocks, the structure in the xenoliths shows them to have done no more than drifted apart. In other cases the xenoliths were intensely rotated and displaced, a process which is exemplified by fig. 21. In this case the granite amounts to more than half of the total surface outcrop and one obtains a general impression of rigid blocks "swimming" in very mobile matter. But also in cases, where the granite is subordinate in the entire dike filling, the total mass must have been highly

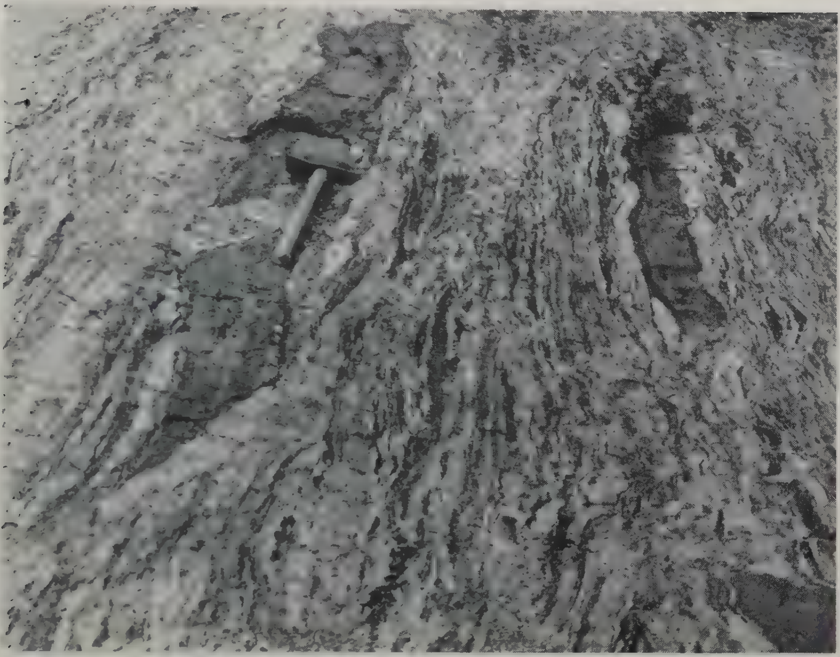


Photo: B. Loberg

Fig. 12. Veined gneiss with inclusions of metabasite representing fractured remnants of originally continuous dikes. Grönö, southeastern shore (the Västervik area).

mobile and behaved as an intrusive rock, which can be exemplified by fig. 22 from the Västervik area. In the sections available the granite generally amounts to only a few percent of the entire dike mass. The appearance of such dikes seems to offer close analogies with those of certain tuff dikes described by Cloos (1941). It is obvious that the mobility of the rock mass in the dikes as exemplified by fig. 22 was caused by the granitic component, which therefore must have been highly mobile.

In the above-mentioned examples only the bodily movements of various rock types have been considered. In summing up, it can be stated that tectonism played an important role in the metamorphic process that lead to the formation of veined gneisses and probably also to granitic rocks, and that physical properties inherent in the various rock components subjected to this metamorphism and also the relative proportions of these components must have had a decisive influence on the resulting structural pattern. Any attempt to propose a model for the evolution must therefore thoroughly take into account the mechanical behavior of the rocks involved in the metamorphism. However, granitization and gneiss formation are also connected with significant mineralogical and chemical changes in the rock masses. Some of these will be treated in the next chapter.

Some Chemical and Mineralogical Transformations Connected with Granitization and the Formation of Veined Gneisses

The deformational processes described in the above paragraph are associated with recrystallization, and generally also with the formation of new mineral species. In the examples presented in figs. 1—8 the metamorphism can be characterized as mainly isochemical. The mineral assemblage andalusite, cordierite, biotite, and feldspars, formed in close connection with the kinetometamorphism, indicate amphibolite facies or possibly high-grade epidote-amphibolite facies conditions. In the last stages of deformation, characterized by the most intense flow of the incompetent rocks (for instance exemplified by fig. 8), a fairly strong sericitization may have occurred, which also attacked the andalusite, and which consequently may represent a potash metasomatism, though of very restricted extension.

Metablastesis in gneiss and granite areas generally indicates more extensive metasomatic processes to have occurred there. In all problems concerning metasomatism one has to face the questions: How much material was added, respectively, how much extracted within a certain rock mass, and how much of the migration can be explained by an interchange of chemical elements

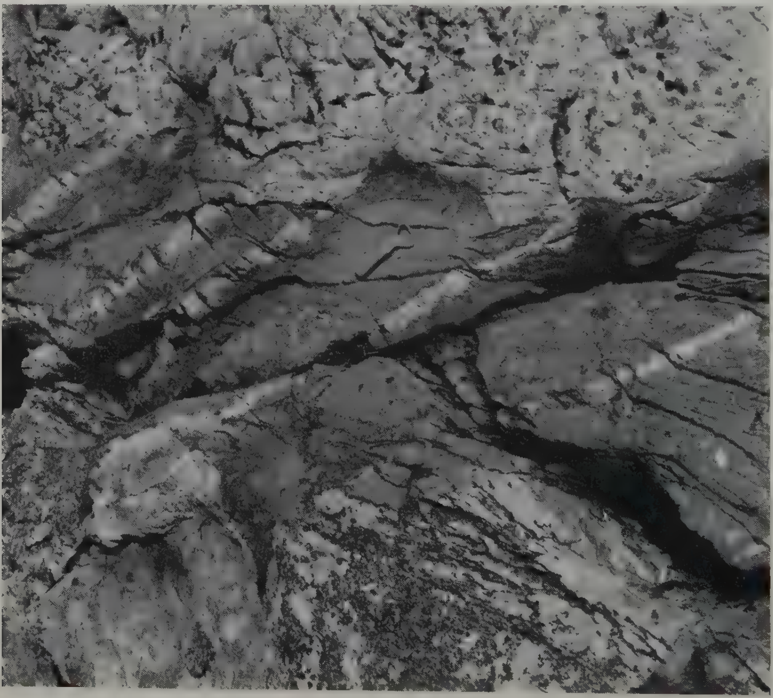


Photo: P. H. Lundegårdh

Fig. 13. Metabasite dike in quartzite. Feldspathized quartzite squeezed into the metabasite parallel to the direction of shear. Grönö, southeastern shore (the Västervik area).

within a restricted rock portion, *i.e.*, what role did metamorphic differentiation play in the metasomatic process under consideration.

The present status of the investigations does not permit a comprehensive discussion of all the chemical and mineralogical processes which can have a bearing on the genetical problems of the gneisses and granites in the Stockholm and Västervik areas. Only two examples will be considered. These illustrate clearly the intimate connection between mechanical and chemical metamorphism.

A. REACTIONS BETWEEN VEINED GNEISS AND METABASITE OR METAARENITE

Inclusions of metaarenite and metabasite in veined gneiss were described on pp. 234—236 and figs 9—11. At these localities the inclusions are invariably surrounded by reaction zones, the megascopically visible width of which varies between 0.5 and 2 cm. Such reaction zones can be taken to indicate a tendency towards restoration of the equilibrium in the total rock mass and can in spite

Table 1. Point counter analyses of metabasite and its reaction zones. Johanneshov, Stockholm area. The figures represent vol.%.

Sample no.	1	2	3
Quartz	—	11.1	22.7
Plagioclase	50.0	22.4	38.6
Hypersthene	20.4	—	—
Grunerite	19.4	41.7	—
Common hornblende	—		—
Biotite	9.2	—	37.9
Sericite	—	22.7	0.7
Ore	1.0	2.1	0.1
% An in plagioclase	75—95	65—70	65—70
Number of counts	1664	2185	1119

Sample 1: Hypersthene-amphibole gabbro.
Sample 2: Sericitized metabasite.
Sample 3: Reaction zone in metabasite bordering on gneiss.

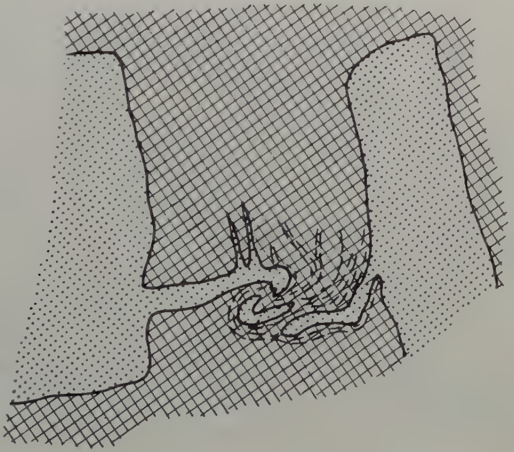


Fig. 14. Sketch showing quartzite squeezed into amphibolite. Southeastern shore of Långö (the Västervik area). Scale 1 : 35. Dots = quartzite; cross-hatching = metabasite. Broken lines superimposed on cross-hatching indicate schistosity.

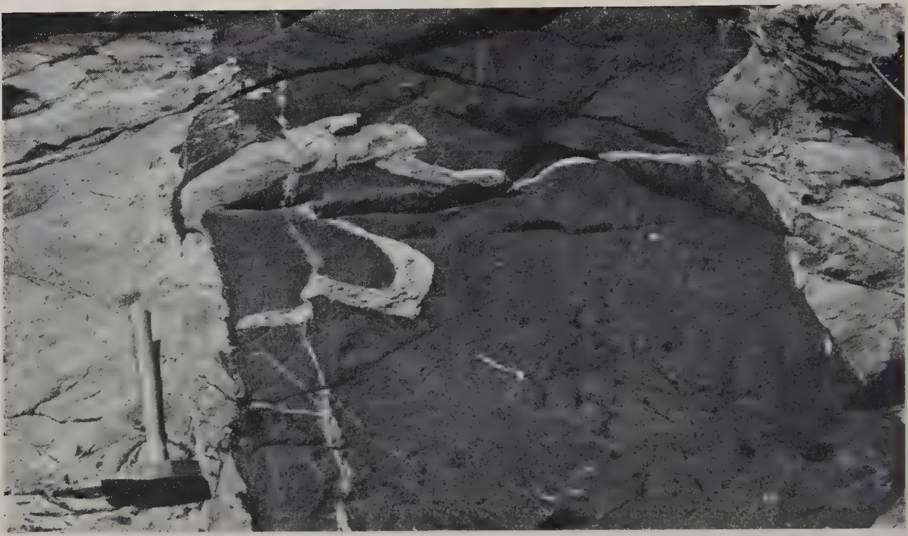


Photo: K. Boström

Fig. 15. Metabasite dike in quartzite. Quartzite grading into pegmatitic veins penetrates the metabasite. Brännskär, southern shore (the Västervik area).

of their slight magnitude give valuable information on the metamorphic processes, viz.: 1. They show that transfer and exchange of matter by diffusion did occur between incompatible rock masses. 2. They give a clear idea of kinds and amounts of migrating components. By comparing the chemical and mineralogical compositions of the two bordering main rock types and of the reaction zones it is possible to establish the addition of elements, for instance from some dispersed phase, and also if changes in the mineral facies took place. 3. The fact, that reaction zones are developed continuously around pieces of rocks which were created through fracturing of competent rocks and plastic flow of the incompetent gneiss mass, discloses that the reactions took place subsequent to the fracturing of the rigid rocks and probably at a stage when the gneiss mass attained its maximum plasticity.

Description: In the plastic gneiss mass (see figs. 9—11) quartz, plagioclase (An_{35}—An_{42}), and biotite are always the chief constituents. Almandite is frequently present and may sometimes occur in fairly large amounts (see Fig. 10). Cordierite or pseudomorphs after cordierite are not uncommon, but such have not been identified with certainty in the cases described below, in which gneiss borders metaarenite or metabasite. Nor was potash feldspar observed in the samples mentioned. On the whole the gneisses with abundant metabasite inclusions seem to be very pure plagioclase gneisses. Significant amounts of microcline were observed in only one thin section. The coarseness of the gneisses and the heterogeneous distribution of their chief minerals make point counter analyses of thin sections meaningless unless they are made in great number. Chemical analyses of two fairly small specimens are presented in Table 2, no. 11939 and Table 4, no. 11933.

Table 2. Spectrochemical analyses[1] of metabasite and its reaction zones. Johanneshov, Stockholm area.

Analysis no.	12093		11938		11937		11939	
	Weight %	Cation Prop.	Weight %	Cation Prop.	Weight %	Cation Prop.	Weight %	Cation Prop.
SiO_2	43.4	722	57	949	62	1,032	70	1,165
TiO_2	1.14	14	1.2	15	1.2	15	0.45	5
Al_2O_3	21.5	422	14.7	288	15.5	304	14.5	284
Fe_2O_3	2.2	27	2.6	32	2.2	27	0.1	1
FeO	11.25	156	9.15	127	6.81	95	4.36	61
MnO	0.16	2	0.1	1	< 0.1	—	< 0.1	—
MgO	6.45	160	5.0	124	2.9	72	2.0	49
CaO	9.4	167	3.8	68	5.0	89	4.1	73
Na_2O	0.6	19	0.43	14	0.47	15	2.46	79
K_2O	0.7	15	3.52	74	3.31	70	1.76	37
H_2O	0.5	28	2.18	127	0.8	44	0.31	17
Total	99.5		99.68		99.6		100.0	
Calculated mineral composition	Plagioclase ... 51.5 % Grunerite + Hypersthene .. 40 % Biotite... 6.5 % Ilmenite 2 %		Quartz .. 17 % Plagio clase ... 11.5 % Grunerite 21.5 % Actinolite 18.5 % Sericite .. 29.5 % Ilmenite 2 %		Quartz .. 36.5 % Plagioclase ... 29 % Biotite... 30 % Sericite .. 2.5 % Ilmenite 2 %		Quartz.... 40 % Plagioclase..... 40 % Biotite .... 17 % Almandite 2 % Titanite... 2 %	
Kind of rock	12093. Hypersthene-amphibole gabbro 11938. Sericitized metabasite 11937. Reaction zone in metabasite bordering on gneiss 11939. Gneiss bordering on metabasite (nos. 11937 and 11938)							

[1] The analyses presented in Table 2 and 4 were performed at the Geochemical Laboratory, Geol. Survey of Sweden, under the guidance of Mr. K. Fredriksson, Fil. lic., Fe_2O_3 and CO_2 were determined at the Chemical Laboratory, Geol. Survey of Sweden, under the guidance of Mrs. Ann Marie Byström-Asklund, Fil. lic. FeO was calculated by subtracting Fe_2O_3 from total iron oxide, which was determined spectrochemically. In those cases where CO_2 was determined the water content was calculated by subtracting CO_2 from total loss by ignition. The inaccuracy of spectrochemical determinations of SiO_2 is comparatively great; the SiO_2-values are therefore generally presented merely as whole percent.

The best preserved amphibolites, as shown in Fig. 11, consist of plagioclase (An_{75}—An_{95}), hypersthene, cummingtonite, grunerite[2], biotite, and ore (see Table 1, sample 1). Generally, however, common hornblende forms an essential constituent of the metabasites, the plagioclase then being partially replaced by sericite. Sample 2 in Table 1 is an amphibolite in which sericite is abundant; it occurs as spots, apparently representing pseudomorphs after plagioclase. Even amphiboles are frequently found to replace plagioclase as fibrous aggregates. The small size of the individual amphibole needles makes it difficult to perform reliable optical determinations for the sake of identification. It seems obvious, however, that both common hornblende and a member of the cum-

---

[2] Provisional optical determinations of the lime-free amphiboles and the spectrochemical analysis show the molecular proportions Fe:Mg to be very close to 1:1, *i.e.* the mireral would correspondend to the boundary between cummingtonite and grunerite. In the tables the mineral is referred to as grunerite in order to conserve space.

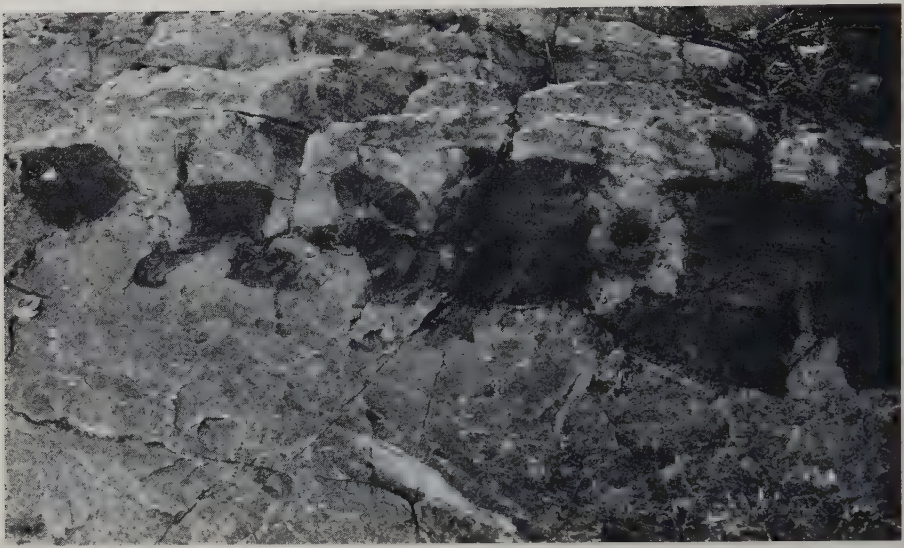


Photo: S. Gavelin

Fig. 16. Metabasite dike in quartzite, fractured and penetrated by mobilized and feldspathized quartzite. 1.5 km S.E. of Ytterhult (the Västervik area).

mingtonite-grunerite series occur, which is also verified by the spectrochemical analysis (Table 2, no. 11938). In the point counter analysis the two amphiboles could not be kept apart with certainty and were therefore counted together as one group.

The megascopically identifiable reaction zone is represented by sample 3 in Table 1. The most conspicuous feature of the reaction rim is seen to be that hornblende has disappeared and considerable amounts of biotite formed instead.

Nos. 11939 (gneiss), 11937 (reaction rim of metabasite), and 11938 (sericitized metabasite) in Table 2 are from the same hand specimen. They show the mineralogical and chemical changes connected with the formation of reaction rims around metabasite pieces. No. 12093 is from a separate metabasite inclusion in which the rock is only slightly sericitized. Sample 1, Table 1, corresponds to analysis no. 12093; the agreement between the point counter analysis and the mineral composition calculated from the analysis is seen to be fairly good.

Samples 2 and 3 in Table 1 would correspond approximately to analyses nos. 11938 and 11937 respectively. It is seen that there is a certain disagreement between the point counter analyses and the calculated mineral compositions. The main reason for this is that the analysed samples are somewhat heterogeneous as regards their mineral compositions. In the reaction zone with quartz, plagioclase, and biotite as chief constituents there is a certain increase of sericite towards the metabasite, and close to the boundary much of the plagioclase is replaced by sericite. Correspondingly, sericitization seems to have been intensified in the metabasite towards the gneiss border. The point counter

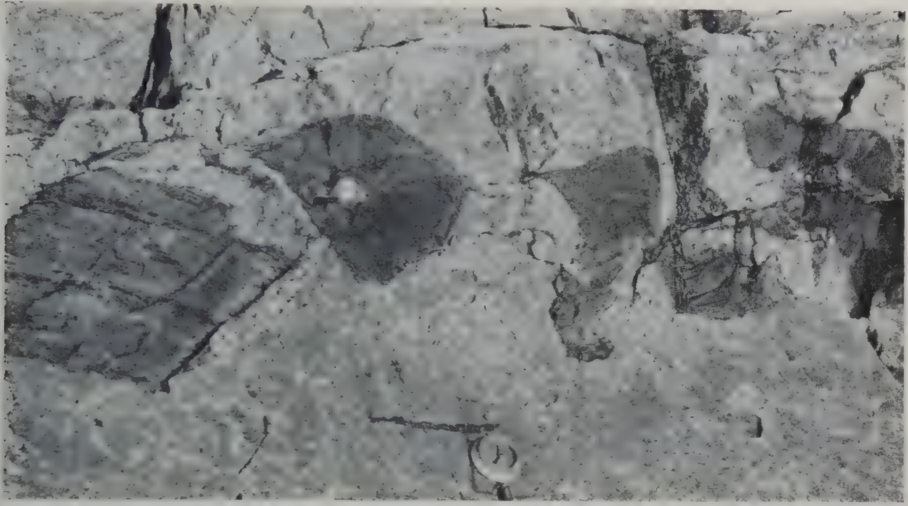


Photo: S. Gavelin

Fig. 17. Detail of the left part of Fig. 15.

analyses were, as far as possible, restricted to those portions of the thin sections which would give the most representative values of the respective rocks. Therefore analysis no. 11938 includes portions in which the feldspars were more intensely replaced by sericite and amphiboles than in the thin section portion analysed by point counter analysis and represented by sample 2 in Table 1. Analysis no. 11937 includes both the "normal" quartz-plagioclase-biotite reaction rim, as exemplified in sample 3, Table 1, and its somewhat sericitized border close to the amphibolite.

In summarizing the results presented in Tables 1 and 2 it can be stated that there is a zone close to the gneiss in which amphiboles are no longer stable, and inside this rim there is a zone in which plagioclase is largely replaced by sericite.

Table 3. Frequency of minerals in gneiss, metaarenite inclusions and reaction zones of metaarenite. Johanneshov, Stockholm area.

	1	2	3	4	5
	Grossularite quartzite	Grossularite-epidote zone	Epidote-sericite zone	Sericite-plagioclase zone	Gneiss
Quartz	+++	+++	+++	+++	+++
Plagioclase				+	+++
Biotite					+++
Sericite			++	++	
Almandite					(+)
Grossularite	+++	++			
Diopside	(+++)	(+)			
Zoisite-epidote		++	+++	++	
Hornblende			+	+	
Calcite	++	++	+	+	

Brackets indicate that the mineral may or may not be present.

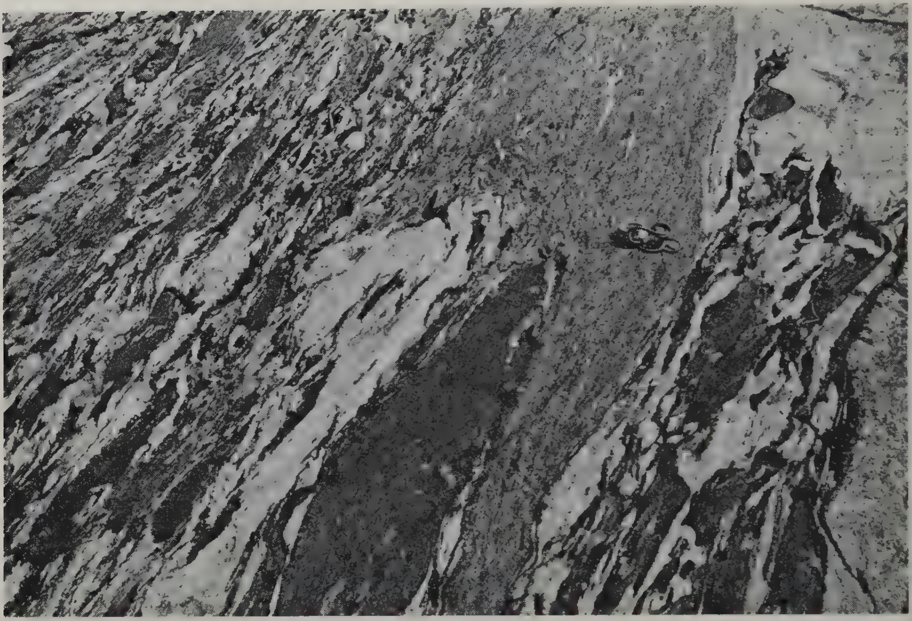


Photo: S. Gavelin

Fig. 18. Irregular veinlets of feldspathized quartzitic material in metabasites occurring in a marked shear zone. In the center a belt of micaceous gneiss. Lökholmen, northern shore (the Västervik area).

The reactions imply mainly an exchange of such elements as are most differently represented in the two main rocks, viz. silicon, iron, magnesium, and to a certain extent also calcium and sodium. In addition, the biotite and sericite zones show that the reactions also involve a certain enrichment in potassium and water.

The reactions between metaarenite and gneiss are shown in Tables 3 and 4. The transitions are more gradual in this case and therefore they are conveniently depicted by the semiquantitative presentation of Table 3. It is founded on a series of slides from five different sections through metaarenite-gneiss contacts. The kernels of the metaarenite inclusions consist of quartz, garnet, sometimes diopside, and calcite (see column 1, Table 3). The physical properties of the garnet, n = 1,745—1,750, a_o = 11,82 kX, show it to be almost pure grossularite. This mineral composition discloses the arenites to represent originally calcareous sandstones which were recrystallized under amphibolite facies conditions.

The first sign of exchange reactions with the gneiss is found to be a replacement of grossularite by zoisite and epidote (column 2, Table 3). First pseudozoisite ($2V\gamma = 46° — 48°$) was formed, which in turn was replaced by epidote, possibly also clinozoisite. The fine-grained and heterogeneous development of the zoisite—epidote minerals makes it difficult to perform accurate optical determinations. Measurements on the universal stage gave: $2V\alpha = 82° — 84°$; $c{:}\gamma = 1 — 3°$. According to Tröger (1952, p. 45) this would correspond to a

Table 4. Spectrochemical analyses[1] of metaarenite inclusions in gneiss, its reaction zones, and bordering gneiss. Johanneshov, Stockholm area.

Analysis no.	12092		11941		11932		11933	
	Weight %	Cation Prop.	Weight %	Cation Prop.	Weight %	Cation Prop.	Weight %	Cation Prop.
SiO_2	59	982	75	1 249	81	1 351	85	1 415
TiO_2	0.32	4	0.23	3	0.28	4	0.27	3
Al_2O_3	13.7	269	7.4	145	8.4	165	8.3	163
Fe_2O_3	2.0	25	1.8	22	0.9	11	0.23	3
FeO	1.44	20	1.1	15	0.96	13	1.30	18
MnO	0.36	5	0.19	3	<0.1	—	<0.1	—
MgO	1.0	25	0.58	14	0.7	17	0.48	12
CaO	20.3	362	10.6	189	6.6	116	2.1	37
Na_2O	0.12	4	0.1	3	0.4	43	2.1	68
K_2O	0.2	4	0.1	2	0.65	14	0.73	16
CO_2	2.46	—	1.39	—	0.12	—	—	—
H_2O	0.24	—	0.11	—	0.28	—	0.1	—
Total	101.1		98.6		100.3		100.5	
Kind of rock	12092. Metaarenite inclusion in gneiss, center part 11941. » » » » , » » 11932. Reaction zone in metaarenite inclusion in gneiss (between 11941 and 11943) 11933. Gneiss bordering on metaarenite (nos. 11941 and 11932)							

---

[1] See Table 2, p. 247.

pistazite with 15—20 % of $HCa_2Fe_3Si_3O_{13}$. On the whole the reactions seem to indicate a slightly increasing iron content in the epidote minerals during the mineralization, which is also confirmed by the fact that the later epidotes have slightly higher birefringences than the earlier ones. Figs. 23 and 24 show that the quartz contents and the structures are similar in the quartz-grossularite rock and in the quartz-epidote rock.

Closer to the gneiss contact sericite and generally also small amounts of a light-coloured actinolitic amphibole appear. Diopside and grossularite are then absent (see column 3 in Table 3). Still closer to the gneiss, plagioclase occurs. It decreases gradually from the gneiss contacts towards the centers of the metaarenite inclusions (see column 4, Table 3). The An content of the plagioclases increases in the same direction. A change from 42 % An in the gneiss plagioclase to 85 % An in arenite plagioclase has been recorded. Sericite generally forms spots which most probably represent pseudomorphs after plagioclase. Sometimes a narrow zone characterized by very intense sericitization (only one or two mm wide) can be observed close to the gneiss-arenite contact. This affects the plagioclase in both the metaarenite and in the gneiss.

In Table 4 the arenite-gneiss reactions are illuminated by spectrochemical analyses. Analyses nos. 12092 and 11941 represent rock portions, which included mineral compositions corresponding to columns 1 and 2 in Table 3. The main difference between these two analyses is that quartz is more abundant in no. 11941. Analysis no. 11932 corresponds in the main to a mineral association as

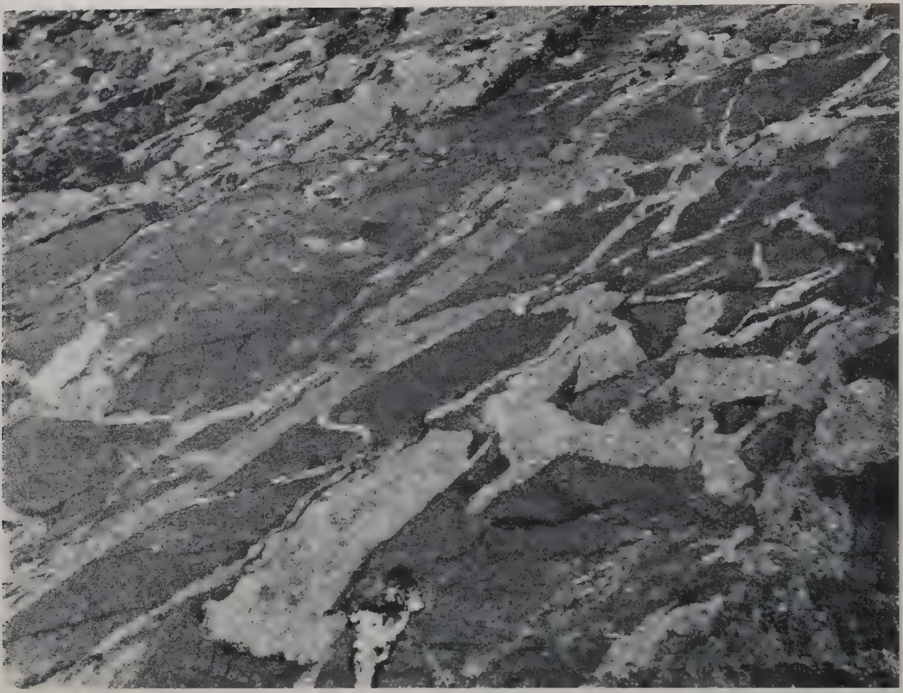


Photo: K. Boström

Fig. 19. Gray granitic or pegmatitic veins in hornblende gabbro. Brännskär, southeastern shore (the Västervik area).

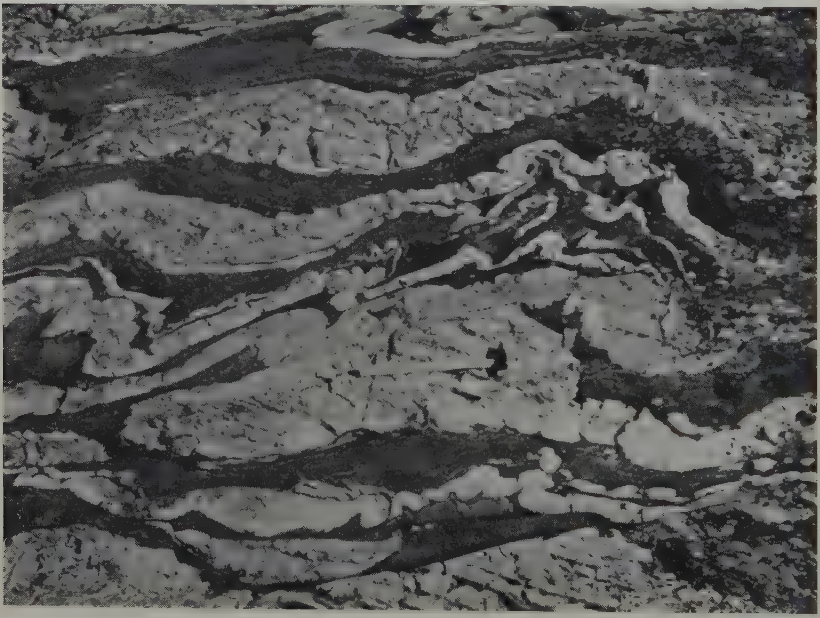


Photo: S. Gavelin

Fig. 20. Folded alternating sheets of quartzite and metabasite, which at this locality display a similar folding competence. St. Vistingsö, northern shore (the Västervik area).

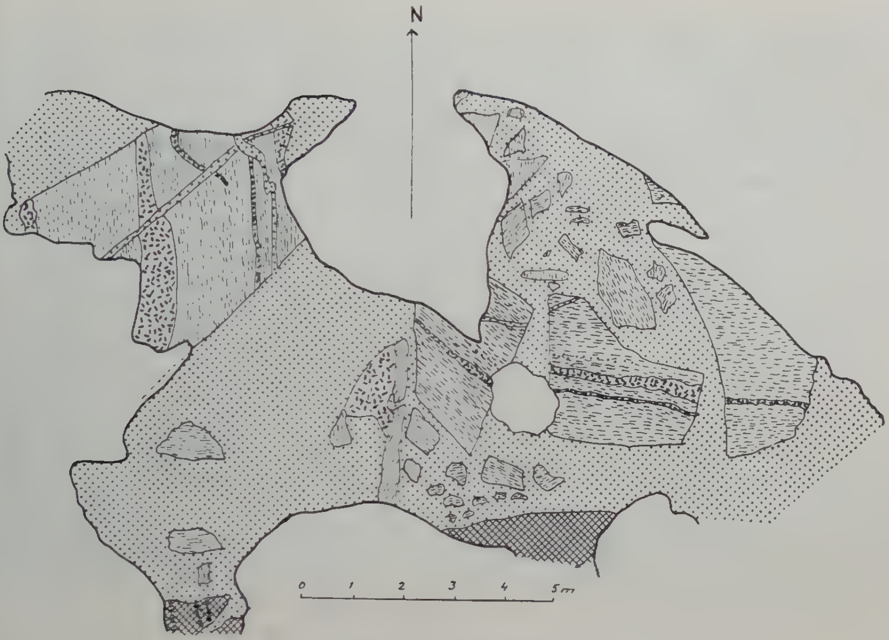


Fig. 21. Stockholm granite (dots) with xenoliths of gneiss (broken parallel lines), which have been rotated during emplacement of the granite. Pegmatite veins older than the granite (short, coarse irregular lines). In the southern part of the outcrop amphibolite (cross-hatching). Hagavägen, Solna (the Stockholm area).

exemplified by column 3 in Table 3, though a slight admixture of the zone represented by column 4 must also have been included in the material analyzed. The analyses as presented in Table 4 demonstrate therefore the general trend of material exchange during the reactions between metaarenite and gneiss. The most conspicuous feature is seen to be the same as was found for the reactions between gneiss and metabasite: The reaction zones represent intermediate compositions between gneiss and metaarenite, and the changes in the arenite composition are particularly obvious when those elements are considered, the concentrations of which are most different when gneiss and "primary" metaarenite are compared. In considering the successive mineral changes demonstrated in Table 3 it is evident that also in this case the reactions involve the formation of hydrous minerals and the enrichment of potassium within a certain stage of the mineralization.

Discussion: The fact that the reaction zones described above have mainly compositions intermediate between the gneiss and the inclusions can be considered a rather trivial result. It is, however, worth consideration, that regional metamorphism under amphibolite facies conditions apparently did not give rise to significant exchange of matter between the chemically different rock portions. The migration of chemical elements as indicated by the reaction zones was realized only when kinetometamorphism was definitely active. The mineralization connected with this migration proceeded under epidote-

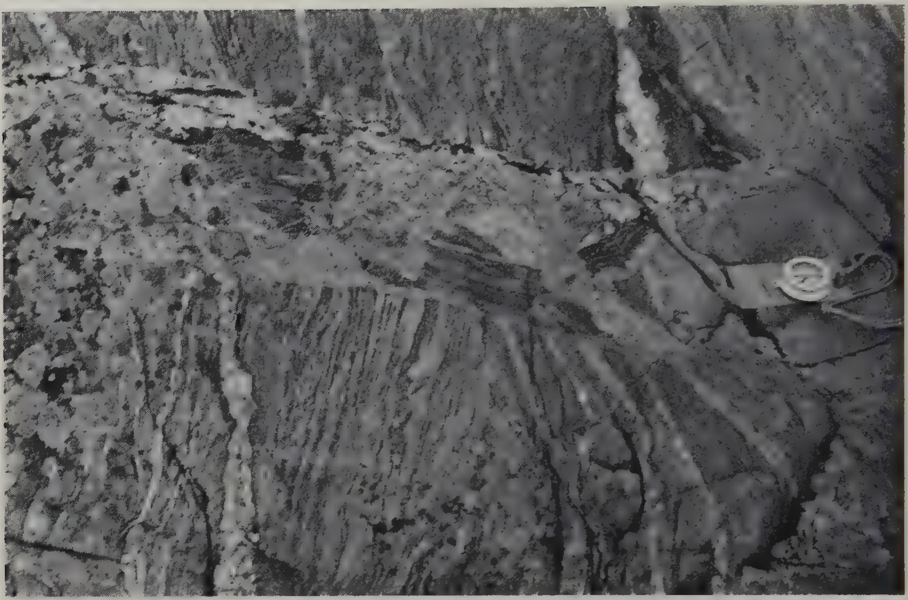


Photo: S. Gavelin

Fig. 22. Veined gneiss cut by dikes of gneiss fragments with subordinate fine-grained microcline granite. Bondeblekskär (the Västervik area).

amphibolite facies conditions as is evidenced by the formation of minerals such as epidote, actinolite, biotite, and sericite. Since pegmatitization and the formation of veined gneisses is closely connected with the kinetometamorphism one may ask if these processes occurred at lower temperatures than the prior, more isochemical metamorphism, which lead to, for instance, grossularite-quartz rocks. It has been emphasized by Yoder (1955), however, that water content and water pressure must be considered very important factors in metamorphism. Mineral formation under similar conditions of temperatures and hydrostatic pressure but with different water pressure or concentration may therefore result in mineral assemblages which are characteristic of different mineral facies. The relations between the veined gneiss mass on the one hand and metabasite or metaarenite inclusions on the other, as described above, could therefore be interpreted as due to the activity of a dispersed phase characterized by an enrichment of water and, to a certain extent, potassium. The occurrence of such a phase was closely connected with the flow of big portions of the rock mass, but it is not possible to decide whether the dispersed phase was the real cause of flow or *vice versa*.

Reactions of the kind described in the present paper are not uncommon in granite and gneiss areas. Härme and Laitala (1955) have presented an example from the coastal area of Southern Finland, where the structural development very much resembles that of the Johanneshov locality. The main difference is that the metabasite of the Finnish locality is surrounded by a rock classified by the authors as a microcline granite. Consequently this contains

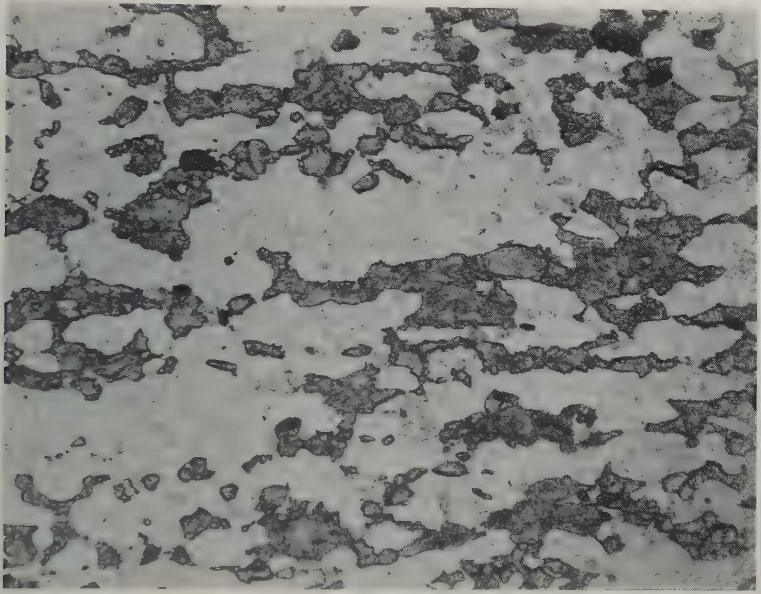


Photo: S. Gavelin

Fig. 23. Quartz-grossularite rock. Metaarenite fragment in gneiss. Nynäsvägen, Johanneshov (the Stockholm area). 1 nic., 40 ×.

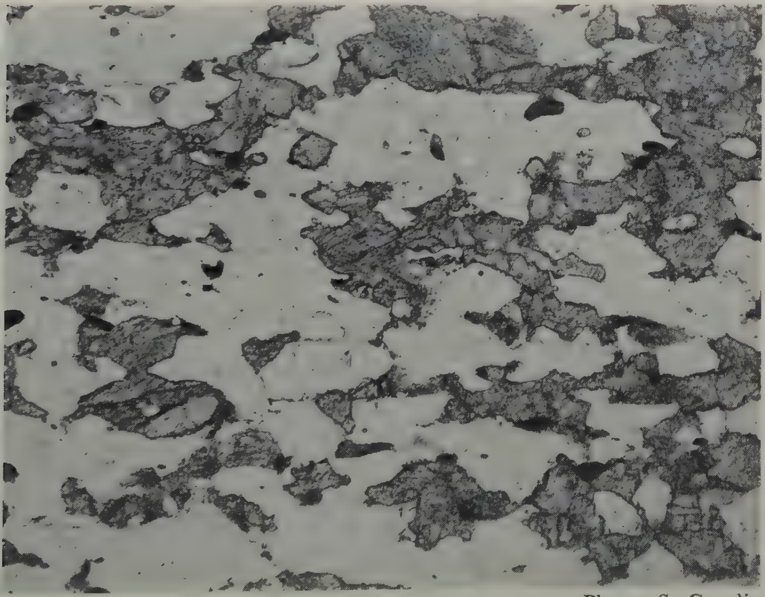


Photo: S. Gavelin

Fig. 24. Quartz-epidote rock with some hornblende. Metaarenite fragment in gneiss. Nynäsvägen, Johanneshov (the Stockholm area). 1 nic., 40 ×.

considerably more potassium than did the plastic rock mass in the Stockholm area.

In considering the mineralogical dissimilarities between the reaction zones and the host rocks the most conspicuous features are exactly the same in the two cases: That is, amphiboles have been completely replaced by biotite. There are also divergences, however. In the examples from the Stockholm area sericite and actinolite seem to represent a significant mineral association (which is also discernible in the reaction rims around the metaarenite inclusions), whereas significant amounts of sericite were not recorded in the Finnish example. It is interesting to note that the "sericite zone" of the Stockholm occurrence has a position corresponding exactly to a zone characterized by a high content of chlorite in the Finnish rock. In the analyses the dissimilarities are reflected by the behaviour of iron and magnesium during the reactions. The biotitization of the amphibolite fragments of the Finnish example took place practically without change in the iron and magnesium contents, but it was connected with some exchange of these elements in the example described in the present paper. It can therefore be concluded that the two reactions developed under somewhat different pt-x-conditions and that this gave rise to different mobilities for iron and magnesium.

B. REACTIONS BETWEEN PURE QUARTZITE AND METABASITE

Description: It was mentioned (p. 238) that pure quartzite occurring as inclusions in metabasite in the Västervik area is sometimes found to pass over into gray pegmatite or granitoid rocks. Fig. 15 demonstrates such a transition. On examining thin sections of those quartzite "veins" which have been squeezed into cracks of bordering metabasite as exemplified by figs. 13—17, it was found that they are always more or less enriched in plagioclase as compared with quartzite at some distance from the adjacent metabasite. When the "veins" display megascopically a pegmatitic or granitic appearance the plagioclase may occur as large idioblasts (Fig. 26). Fig. 25 shows the texture of a quartzite inclusion in metagabbro close to the vein shown by fig. 26. It is seen that the grain size and texture of the quartz mass between the plagioclase idioblasts of the "pegmatitic" vein are practically identical with those of the quartzite inclusion as demonstrated in fig. 25. The "pegmatite" very clearly appears to represent a feldspathized quartzite.

In the other cases, exemplified by figs. 13 and 14, plagioclase in the feldspathized veins may form smaller porphyroblasts (Figs. 27 and 28) or more fine-grained aggregates, which appear frequently as streaks parallel to the direction of flow (Figs. 29 and 30). The "pegmatized" quartzite demonstrated by fig. 15 has both granular masses and large metablasts of plagioclase. The latter show sometimes a peculiar division into fields with somewhat varying optic orientation. The size and fabric of these fields are similar to those of the surrounding quartz mass. It might therefore be questioned if this texture displays the original quartz grains of the quartzite. On the other hand, it may

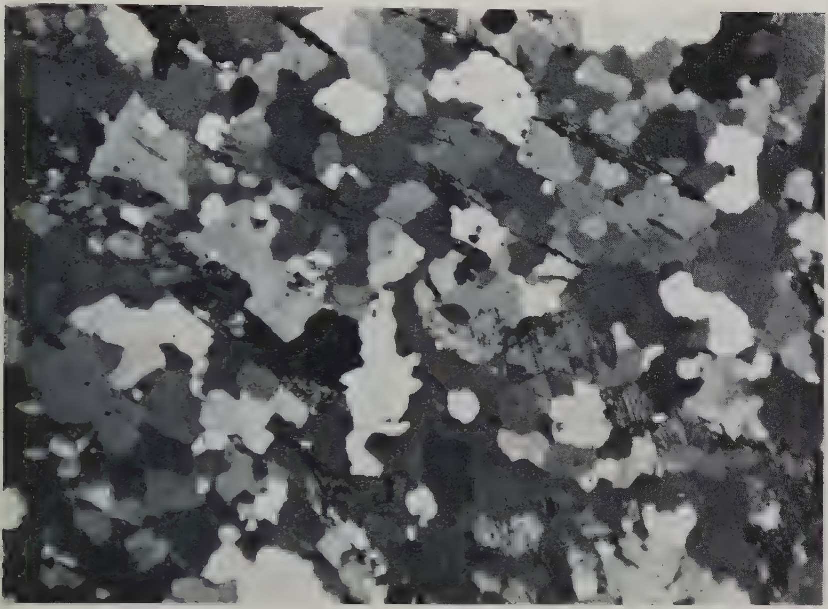


Photo: S. Gavelin

Fig. 25. Quartzite. Xenolith in hornblende gabbro (no. 77, Table 5). Mössan (the Västervik area). + nic., 12 ×.

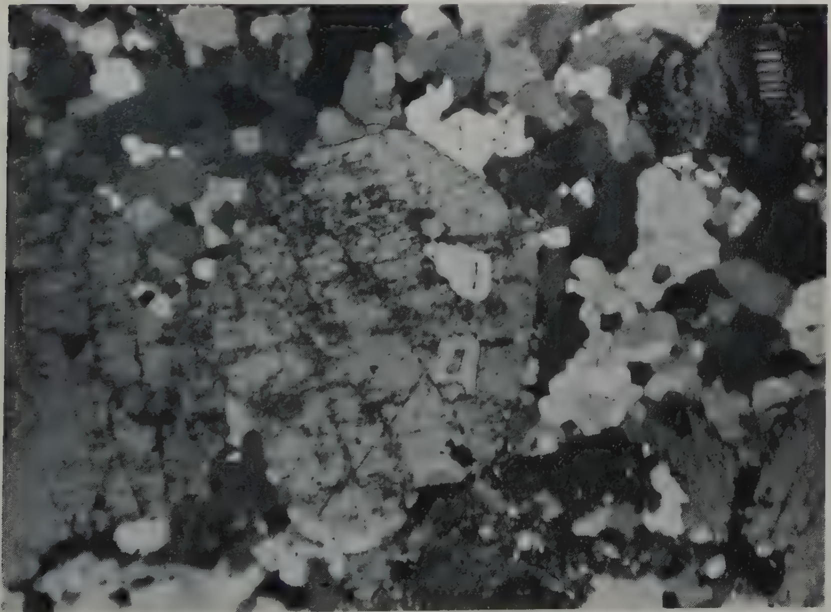


Photo: S. Gavelin

Fig. 26. "Pegmatitic" vein in hornblende gabbro (no. 78, Table 5). Large idioblasts of plagioclase in granoblastic quartz. Mössan (the Västervik area). + nic., 12 ×.

Table 5. Point counter analyses of mobilized and feldspathized quartzites and adjacent quartzite from the Västervik area. The figures represent vol.%.

Thin section no. (in the Västervik series)	I		II		III			IV		V		
	31	137	133	134	71	135	136	131	132	76	77	78
Quartz	97.9	39.6	90.3	39.8	64.0	83.3	49.2	81.0	75.0	96.1	88.0	44.8
Plagioclase	0.7	56.6	0.4	58.9	<0.1	10.7	44.7	8.5	20.0	2.7	5.5	50.3
Microcline	—	—	6.3	—	31.8	—	—	—	—	—	—	—
Biotite	—	2.1	0.3	2.2	1.7	2.1	1.7	5.1	4.4	0.3	5.4	1.5
Sericite	0.9	1.4	2.5	0.5	1.4	1.1	0.9	4.8	0.3	0.6	0.4	2.0
Chlorite	0.2	0.2	—	0.4	0.4	0.3	0.4	—	0.3	0.1	0.5	0.7
Epidote	—	—	—	0.1	—	1.6	2.0	—	—	—	—	—
Calcite	—	0.1	—	<0.1	—	—	0.2	—	<0.1	<0.1	—	—
Tourmaline	—	—	—	—	—	—	—	0.3	—	0.2	<0.1	—
Andalusite	—	—	—	—	—	—	—	—	—	—	—	<0.1
Other assessories	0.3	<0.1	0.2	0.1	0.7	0.5	<0.1	0.2	0.5	—	<0.1	<0.1
% An in plagioclase[1]	Ab	25—30	Ab	11—14	—	Ab	25—30	Ab	27—29	55—65	50—52	38—40
Number of counts	7000	4 255	6500	3 395	3 695	3109	2 912	6315	6 542	9 025	4 233	4 222

I. S.W. of Spårösund: No. 31. Coarse quartzite. No. 137. Veins in metabasite (see fig. 13).
II. Southeastern Langö: No. 133. Quartzite from big xenolith in metabasite. No. 134. Quartzite veins in metabasite (see Fig. 14).
III. Southern shore of Brännskär: No. 71. Quartzite with cross-bedding. No. 135. Veins of quartzite in metabasite. No. 135. Pegmatized veins in metabasite (see Fig. 15).
IV. S.E. of Ytterhult: No. 131. Quartzite, 1 m from metabasite. No. 132. Feldspathized quartzite squeezed into metabasite (see Figs. 16 and 17).
V. The Mössan island: No. 76. Quartzite with weak banding close to hornblende gabbro. No. 77. Xenolith of quartzite in hornblende gabbro. No. 78. Gray granitic or pegmatitic vein in hornblende gabbro.

[1] Ab denotes albitic plagioclase, in which sericitization has made accurate optical determination of the An content impossible.

also be due to postcrystalline cataclastic deformation. Still there are many instances where plagioclase is seen clearly to replace quartz, as shown in fig. 31. Furthermore, in all cases the quartzite fabric is clearly identifiable in the feldspathized and mobilized rocks.

The metabasites examined under the microscope contain common green hornblende, plagioclase, and biotite as essential constituents. In the coarse-grained types, occurring as larger and more irregularly-shaped masses than the dikes and sills, the plagioclase plates indicate the primary gabbro texture. Quartz is generally present but in varying amounts; it is very irregularly distributed and may have been introduced from adjacent siliceous sediments. Ore minerals, small amounts of epidote, sericite, and sometimes calcite were also observed. The plagioclase composition was found to vary between An_{45} and An_{52} in a metagabbro; in a comparatively well-preserved basite dike it was found to vary between An_{70} and An_{75}.

Table 5 gives five examples of differences between the mineral compositions of mobilized and feldspathized quartzites and adjacent non-feldspathized or

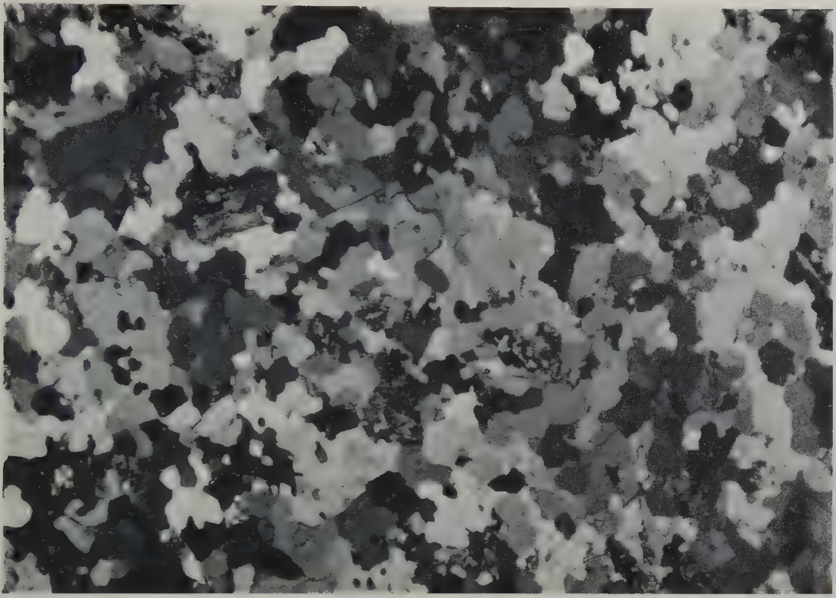


Photo: S. Gavelin

Fig. 27. Quartzite 1 m from broken metabasite dike (Figs. 16 and 17, sample no. 131, Table 5). 1.5 km S.E. of Ytterhult (the Västervik area). + nic., 12 ×.

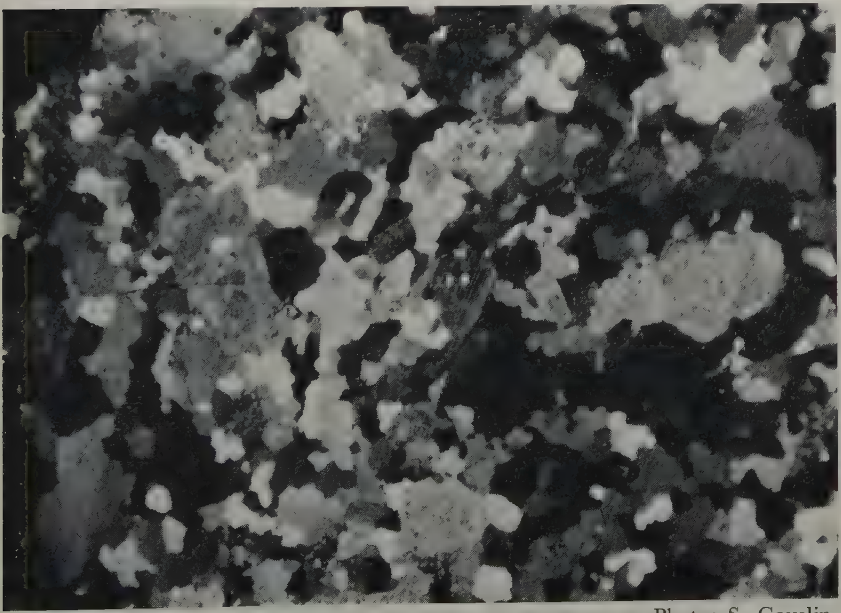


Photo: S. Gavelin

Fig. 28. Mobilized and feldspathized quartzite (Figs. 16 and 17, sample no. 132, Table 5). 1.5 km S.E. of Ytterhult (the Västervik area). + nic., 12 ×.

only weakly feldspathized quartzite. The figures represent point counter analyses of thin sections, and since the feldspar percentages may vary considerably over small distances in a single vein of feldspathized quartzite they represent only very approximate measures of the compositions. Since the primary rocks have simple compositions (almost pure quartzites), the general trend of the mineralogical changes is clearly expressed. It is seen that in the main the process involves a replacement of quartz by plagioclase. The An contents of the plagioclases are highly variable and seem to be dependent on local conditions. The plagioclase of the quartzite portions from which veins were squeezed into metabasites is generally found to be more albitic than that of the intensely feldspathized veins. It is quite possible, and sometimes very probable, that also the plagioclase outside the mobilized veins was formed through a weaker feldspathization. This would mean that sodium would have a tendency to migrate slightly more readily than calcium.

The behavior of potassium is interesting. Sample no. 133, Table 5, representing the "primary" quartzite, is seen to contain 6.3 % microcline, whereas the mobilized and feldspathized quartzite is definitely free from microcline. The same transformational trend is indicated by nos. 71, 135, and 136. Nos. 135 and 136 both represent mobilized quartzite (see figs. 15 and 16). No. 71, which is seen to contain a considerable amount of microcline, is not from the immediate vicinity of nos. 135 and 136 but was sampled to represent the upper, generally cross-bedded quartzites in this part of the area. Additional samples from the same part of the Västervik area have shown these types of quartzites to contain microcline in varying amounts and since metamorphism there is low it was assumed that the feldspar occurs principally as a primary constituent of the sediment. From the above considerations it seems probable that microcline when present in the "unmoved" quartzites, potassium was replaced by sodium during such feldspathization as was connected with the plastic flow of quartzite into metabasite.

Discussion. The origin of the material causing the described type of feldspathization requires consideration of the following:

1. Feldspathization is restricted to, or at least definitely intensified in those parts of the quartzites which border metabasitic rocks and which have been most intensely deformed by plastic flow.

2. The newly-formed feldspars are exclusively plagioclases; when potash feldspar was present in the deformed quartzite it was consumed during the formation of plagioclase.

3. No granitic, granodioritic, or tonalitic intrusive whatever occur in such a manner that the feldspathization could be explained as a result of the transfer of matter from a magma.

4. There are no signs of a regional feldspathization of the kind described above, at least within the areas from which the examples were taken. On the contrary, where migmatitization and granitization attain a more regional extension, its most characteristic features seem to be potash metasomatism. Fig. 13 and samples nos. 31 and 137 represent a locality, which is very illuminative

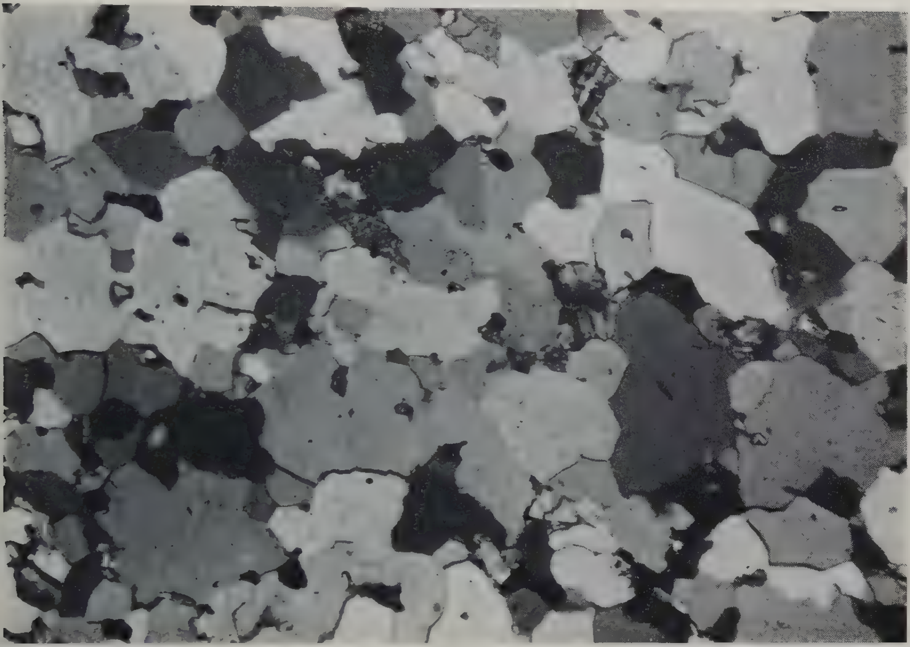


Photo: S. Gavelin

Fig. 29. Xenolith of quartzite in metabasite. (See Fig. 14 and sample no. 133, Table 5). Southeastern shore of Långö (the Västervik area). + nic., 40 ×.

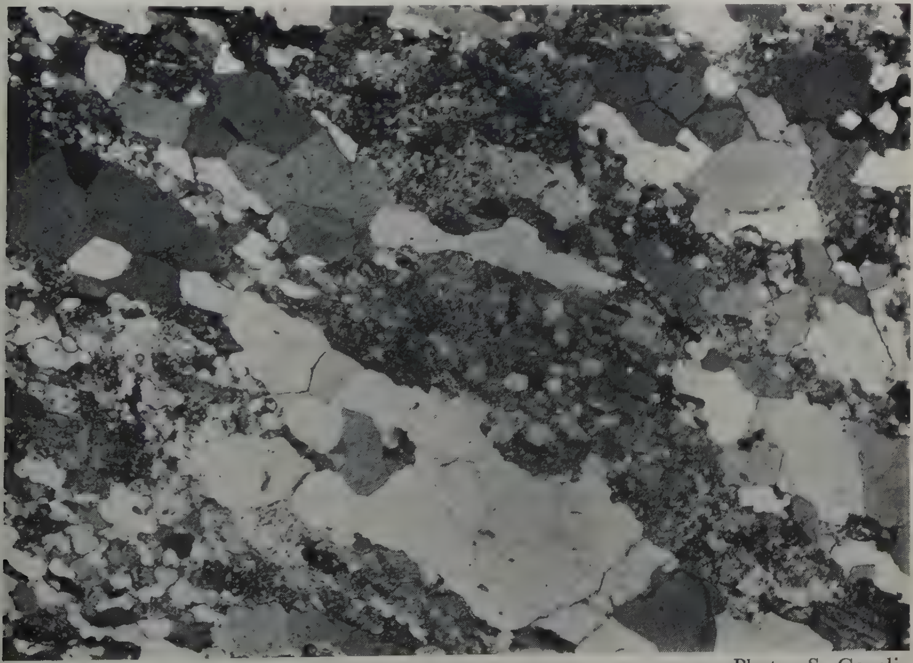


Photo: S. Gavelin

Fig. 30. Mobilized and feldspathized quartzite (Fig. 14 and sample no. 134, Table 5). Southeastern shore of Långö (the Västervik area). + nic., 40 ×.

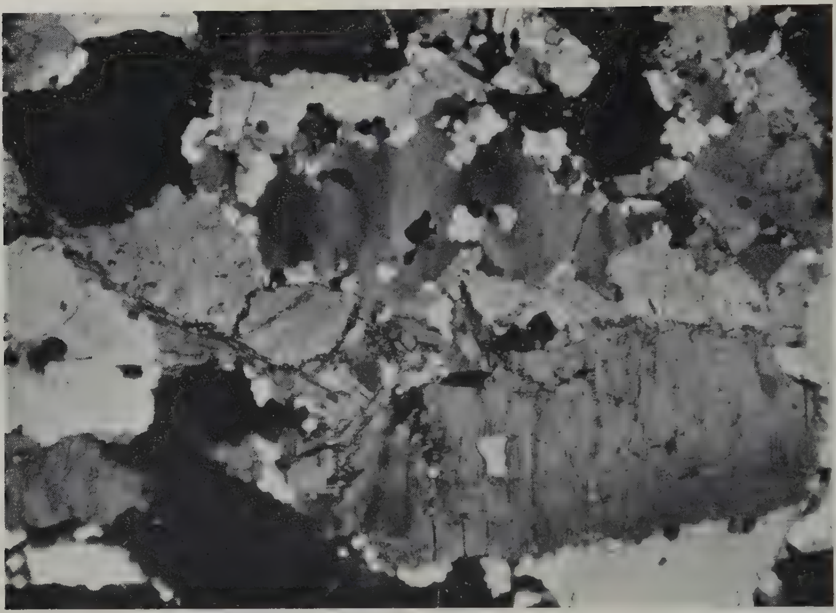


Photo: S. Gavelin

Fig. 31. Plagioclase replacing quartz in mobilized and feldspathized quartzite veins (See Fig. 13 and sample no. 137, Table 5). Grönö, S.W. of Spårösund (the Västervik area). + nic., 12 ×.

in this respect. The feldspar in the mobilized quartzite is exclusively plagioclase, but belts of veined gneisses alternating with the quartzite always contain abundant microcline in their pegmatitic portions. On traversing the rock sequence which includes the locality illustrated by fig. 13, the general impression is that the predominant chemical metamorphism in this area was potash metasomatism.

From the above statements the following conclusions may be drawn. The migrations of material connected with feldspathization of the quartzites must have been local and have represented some kind of metamorphic exchange within a limited rock portion. The metabasites provide the only possible source for the amounts of sodium, calcium, and aluminium necessary for the formation of feldspars in the mobilized parts of the quartzites. The metasomatic character of the feldspathization indicates the process to have proceeded as an intragranular diffusion of ions or molecules between two incompatible rock types, viz. quartzite and metabasite. There is no evidence of water or other volatiles to have played any essential role in the process. Sericitization is weak and scapolite has been observed only in one case. If volatiles were present at all they were most probably restricted to some quantitatively insignificant intragranular phase. Even such a phase may certainly have had an important catalytic influence on the reactions, but it could not take an active part as a constituent in the reactions. This is a clear difference as compared with the reactions connected with the formation of metabasite inclusions in veined gneiss in the Stockholm area described on p. 245—256.

Whereas an addition of certain elements necessary for the formation of plagioclase is clearly evidenced in the feldspathized portions of the quartzite, no indication of a corresponding depletion of the same elements from the bordering metabasites can be observed megascopically. Thus, reaction zones similar to those around the metabasite xenoliths in veined gneisses from the Stockholm area (*cf.* pp. 245—246) have not been observed. It must be remembered, however, that the quantities of feldspathized rock are generally subordinate as compared with those of metabasite. The field data alone would therefore indicate that the ions introduced into the quartzites during the feldspathization were derived from such large masses of metabasite that a change of its original mineralogical composition is not now palpable. On the other hand, the metabasites have not yet been examined in great detail, and it is possible that future complementary investigations may give results similar to those presented by Reitan (1955, 1958, 1959) in his studies on a pegmatitization, which in many respects resembles that described here, *i.e.* that also basic rocks in the proximity of quartzites display significant mineralogical and chemical changes.

The diffusion which caused feldspathization in the quartzites was apparently realized through pressure gradients and probably stimulated by the mechanical result of pressure (fracturing of the more competent and flow of the less competent rock). The role of pressure gradients in the metamorphism of deeply buried rock masses have been discussed by several petrologists. Ramberg has in many papers emphasized the importance of this factor for the transfer of matter and for reactions, which are believed to have occurred in connection with deep-seated metamorphism (see for instance Ramberg, 1952, pp. 76—228). Some of the pegmatites in West Greenland discussed by Ramberg (1955, 1956) and presented by him as examples of the above-mentioned processes are strikingly similar to those here described from the Västervik area. This also holds true for the pegmatites described by Reitan (1956, 1958, 1959). Both Ramberg and Reitan interpret the formation of such pegmatitic veins in rigid femic rocks as a result of metamorphic differentiation caused by pressure gradients, which in turn were created when the rigid rocks yielded by fracturing. Matter diffused into the low-pressure areas ("pressure shadows") where feldspars crystallized. Ramberg (1956, pp. 196 –197 and 210) states, however, that plastic flow of incompetent rocks also contributes to the formation of veins. In the case of the veins of the Västervik area it is quite obvious that the migration of matter was primarily that of a bodily flow of pure quartzite. This flow was, however, invariably connected with plagioclase invasion. Since bodily flow of low-competent rocks and chemical potentials both tend to transport the material of the veins towards low pressure portions of the rock sequence, both bodily migration and diffusion act in the same direction. If diffusion proceeds as intragranular transport in the solid state one can easily imagine that the flow facilitates the metamorphic differentiation process. Field data sometimes give the impression that the movements acted like the opening of a sluice, making possible for matter to "flow" suddenly into the quartzites and form feldspar.

Furthermore, it is a general experience that the most "granite-looking" veins, *i.e.* those veins which are most homogeneous regarding mineral proportions, grain size, and megascopic appearance, are those, which have the most conspicuous intrusive occurrence and consequently have attained the highest degree of mobility. Thus there seems to be a certain correspondence between increasing feldspathization and homogenization on the one hand and increasing ability to flow on the other.

Summing up, the feldspathization of quartzites in the described examples is found to have been caused by the cooperation of the following circumstances:

1. The existence of chemically incompatible rocks bordering on each other (quartzite and metabasite).
2. The interaction of strong compressive and tensile stresses on rocks with different physical properties (with mutually different folding competence), which were apt to create sizeable pressure gradients.

Temperature must also have been a decisive factor, but what really started the reactions was stress or, more adequately, its manifestations, viz. the flow of incompetent and the fracturing of competent rocks, and the formation of strong pressure gradients. It is worth recalling that at least some of the incompatible rock masses prior to the processes discussed above bordered onto each other at much higher temperatures, probably 1,000—1,200° C, without exchange reactions being realized, viz. when basaltic magma was intruded in the arenaceous sediments. The relatively small size of the basic intrusions and rapid cooling would certainly not permit us to expect great thermal effects, but we may conclude that exchange reactions which could not take place through sudden heating are readily realized under the influence of stress action at far lower temperatures.

The discussion of the feldspathization of quartzites has been restricted to those cases in which it is conspicuously connected with kinematic metamorphism and where the bordering primary rocks were generally very poor in potassium. It should be mentioned, however, that within the Västervik area a kind of feldspathization is also encountered which involves an introduction of microcline into the quartzites. This feldspathization sometimes evolves as diffuse veinlets and occurs within areas where potassic granitoids or pegmatites are abundant. Provisionally such granitoids and pegmatites have often been interpreted as granitized and mobilized graywacke sediments. The mode of occurrence much resembles an example of feldspathization in a quartzite from central Finland as presented by Härme (1959). From Härme's description one receives the impression that the feldspathization is directly connected in space with dikes of homogeneous granite in the quartzites. Generally no such direct connection occurs in the Västervik area, and since the process there is closely connected with the genetical problems of the potassic granites and veined gneisses it will be discussed in a later article in which field data concerning these rocks can also be presented.

Some General Considerations on the Role of Kinetometamorphism in the Formation of Veined Gneisses and Granites

Any attempt to survey the "granite controversy" as it has appeared in the geological literature over some 80 years or more must repeatedly face the intriguing question: How is it that skilled investigators can arrive at such different conclusions from what seems to be identical, or at least similar, data. Several authors, for instance Read (1957), Eskola (1955, 1956), Walton (1955), Mehnert (1959) have recently tried to answer this question by collecting and weighing arguments for different ideas concerning the formation of granites and gneisses. From these surveys one may often gain the impression that much of the confusion has been caused by the lack of a stringent nomenclatorial system. For instance, fundamental conceptions such as "magma" and "granite" are often not used in the same sense by all workers which, of course, must complicate discussions. From the surveys mentioned above it is clear, however, that in spite of the fact that a "granite controversy" still exists, the diverging points of view are at present not as incompatible as they were some 20 to 30 years ago.

Mehnert *(op. cit.)* points out, for instance, that many of the advocates for the magmatic origin of a certain granite are forced to assume the occurrence of late-magmatic metasomatism in order to explain certain textural features; he states that this circumstance has contributed towards bringing the magmatic and transformistic views closer together. This means also that there is a certain amount of agreement as regards the conception that granite formation is not generally to be interpreted as a single process. It is evident, from the above surveys, that quite different factors must be considered as possible causes for the origin of "granite-looking" rocks or granitoids. I think that Read's statement "there are granites and granites" could be extended in the following way: Granite formation may often be the result of a very complex process, in which various factors and steps of mineral formation, the transfer of matter etc., may contribute to the final result. The end product formed depends on which of the factors was dominant on a particular occasion.

It is also clear that the great accumulation of both field and experimental data have now made it possible to discuss the problems on a more factual basis. A common statement made in surveys of the granite problem is that the technique applicable to the study of phase equilibria at high temperature and pressure, and also in the presence of water, render safer bases for interpretations of the mineral-forming processes which are postulated to have been active. Much data on the stability relations of minerals partaking in such reactions have been presented in recent years, and many attempts have been made to apply these results to reactions considered to have occurred in Nature. This requires some kind of model, however, which necessitates assumptions about the conditions of evolution. Discussions of the chemical processes leading to granite and gneiss formation are often founded on a model which involves a more or less static process. Any investigator of gneiss problems knows, however, that interpretations of the genesis of gneisses are highly dependent on the possibility of making reliable structural and textural analyses. If, therefore, the genetical problems of a granite in an area are intimately connected with those of associated gneisses, it is evident that the chemical processes leading to granite formation must be discussed with due consideration to the pre-granite tectonic evolution.

The role of kinematic metamorphism in the genetic problems of granites and gneisses has been emphasized by several investigators. Particularly Wegmann has, on several occasions, stressed the necessity of thorough structural analysis in interpretations of the genesis of granitoids and gneisses. (His main ideas are summarized in papers published 1953, 1955, 1956 and 1958.) Reynolds (1954) discussed the role of fluidization in granitization. Both authors pointed out that sharp contacts and dikes of granite are only indications of the relative mobility of the rocks in consideration but can say nothing about the existence of a true magma. Kranck (1957) has drawn attention to the analogies between the patterns, developed both on a large and a small scale, often met with in gneiss areas, and those, which can be studied in large scale sections through mountain ranges characterized by large thrust sheets, for instance, the Alps. The fact that solid rocks are capable of flowing under certain stress conditions make sure interpretations of the consistency of the material which was moved bodily a very intricate task.

The examples discussed in the present paper were given to demonstrate a close connection between kinetometamorphism and metasomatism. It is seen that kinetometamorphism is frequently a definitely selective process, and it is postulated that this fact may be an important factor in interpretations of the selective development of metasomatism connected with the formation of granites and gneisses. It has frequently been assumed that selective metasomatism in a heterogeneous rock sequence was caused mainly by the variations in chemical composition in various parts of the rocks. It seems probable, however, that the physical properties of the rocks may sometimes have a still more decisive influence in this respect.

This does not mean that kinemetamorphism alone could account for such processes as feldspathization and pegmatitization in the examples discussed, thermometamorphism and particularly volatiles must also have been active. The kinetometamorphism as exemplified by figs. 4 and 6—8, for instance, did not lead to granitization or pergmatitization. On the other hand, those adjacent areas which are characterized by veined gneisses display clear evidence of having been caused by a more intense and more regional kinetometamorphism. The structural patterns of veined gneisses are often interpreted as having been formed by pegmatitic material which soaked the older rocks and thereby gave the entire rock mass a high plasticity. As an alternative and tentative hypothesis it is proposed that flow caused by differential stress may sometimes create conditions such that diffusion and reactions between incompatible rocks in a heterogeneous rock sequence are realized. In the higher levels of the crust kinetometamorphism is frequently found to occur without diffusion or reactions such as those characteristic of gneiss areas; for example in glide zones under thrust sheets in a mountain range. Therefore, one must assume such a process as outlined above to require an environment which, with respect to pt-conditions, facilitates the formation of feldspars, *i.e.* probably represents deeper levels in the crust.

It was mentioned that the examples discussed in the present paper may be taken to indicate that feldspathization and diffusion of certain elements were stimulated by flow of the mobile rock portions. It was stated that the processes developed in connection with increasing fluidization of certain parts of the rocks. Such a fluidization process could of course originate by the selective formation of anatectic melts such as were produced experimentally by Winkler (1957, 1958, 1960) by heating clays under 2,000 atm. H_2O-pressure. The initial stages, at least, in the examples discussed here must have proceeded without contributions of anatexis, however, but water was sometimes probably an important factor and may have contributed considerably to the fluidization.

The role of water as a catalyst in metasomatic formation has been emphasized by many investigators. The occurrence of water, even in very small amounts, is therefore believed to facilitate greatly the diffusive transfer of matter. As concerns such kinds of mineralization as feldspathization, which is one of the most important processes in granitization, a very interesting hypothesis has been proposed by Gabrielle Donnay, Whyart, and Sabatier (1959). They found experimentally that water acted as catalyst in the substitution of Al—Si and that the formation of silicates through the diffusion of Si and Al in the solid state is thus greatly facilitated by the presence of even very small amounts of water. A mechanism was proposed by these authors, which involves that OH^- ions enter the SiO_4-tetrahedra in silicate structures, thus creating strong polarizing effects which weaken the bonds and facilitate a migration of Si and Al through the lattices. If this hypothesis holds true it is evident that such processes as feldspathization must be stimulated in the presence of water. Since many kinds of mineral formation which precede the feldspathization and pegmatitization, of, for example, an argillaceous sediment involve a release of water, we may there find a clue to the mobility of Si and Al during such processes. The relationship between kinetometamorphism and the migration of elements in the mineral-forming processes which sometimes lead to the development of veined gneisses, pegmatites, and granitoids, may therefore be interpreted in the following way: Plastic flow of rocks facilitates diffusion of the water released by the formation of anhydrous minerals; this water may under favourable pt-conditions cause

1. the diffusive migration of elements and the formation of new silicates (for example feldspathization) and
2. increased fluidization of certain bodies of rock which leads to the formation of dikes or veins of granitic or pegmatitic appearance.

It is suggested by the present author that many problems which come under the heading of "granite controversy", for example the "space problem", the interpretation of fairly sudden transitions from gneiss to non-gneissic rocks etc., may be readily understood by assuming a mechanism, which involves a close connection between kinetometamorphism, with the bodily movement of material, and metasomatic exchange with the diffusion of ions.

ACKNOWLEDGMENTS

The field work in the Västervik area, which was part of the preparations for the excursions connected with 21st International Geological Congress, was financially supported by the Geological Survey of Sweden. The spectrochemical and chemical analyses were performed at the laboratories of the Geological Survey. The author is indebted to the former Director of the Survey N. H. Magnusson and to the present Director K. A. Lindbergson for their kind interest in the work, as well as to Mr. K. Fredriksson, Fil. lic., and Mrs. Ann Marie Byström-Asklund, Fil. lic., for their assistance with the spectrochemical and chemical analyses.

REFERENCES

G.F.F. = Geologiska föreningens i Stockholm förhandlingar
S.G.U. = Sveriges geologiska undersökning (Geol. Survey of Sweden)

Cloos, H., 1941: Bau und Tätigkeit von Tuffschloten. Untersuchungen an dem Schwäbischen Vulkan. Geol. Rundschau, 32, p. 709—800.

De Sitter, L. U., 1956: Structural Geology. New York, London, Toronto.

Donnay, Gabrielle, Wyart, J., and Sabatier, G., 1959: Structural mechanism of thermal and compositional transformations in silicates. Zeitschr. Krist., 112, p. 161—168.

Du Rietz, T., 1949: Västervikskvartsitens granitisering (English summary). G. F. F., 71, p. 91—112.

Eskola, P., 1955: About the granite problem and some masters of the study of granite. Bull. Comm. géol. Finlande, 168, p. 117—130.

— 1956: Postmagmatic potash metasomatism of granite. Bull. Comm. géol. Finlande, 172, p. 85—100.

Gavelin, S., and Lundegårdh, P. H., 1960: Development of gneisses and granites in Southern Sweden. XXI Internat. Geol. Congr. Guide to excursion nos. A 28, C 23, edited by S. G. U.

Goguel, J., 1952: Traité de tectonique. Paris.

Härme, M., and Laitala, M., 1955: An example of granitization. Bull. Comm. géol. Finlande, 168, p. 95—99.

Härme, M., 1959: Examples of the granitization of gneisses. Bull. Comm. géol. Finlande, 184, p. 41—58.

Hjelmqvist, S., 1938: Über Sedimentgesteine in der Leptitformation Mittelschwedens. S. G. U., Ser. C, No. 413.

Kranck, E. H., 1957: On folding-movements in the zone of the basement. Geol. Rundschau, 46, p. 261—282.

Laitala, M., see Härme.

Loberg, B., 1959: Petrofabric of some varieties of Stockholm granite and associated rocks. Stockholm Contrib. in Geology, III, p. 103—126.

Lundegårdh, P. H., see Gavelin.

Magnusson, N. H., 1936: Berggrunden inom Kantorps malmtrakt. Summary: The veined gneisses of the Kantorp ore district. S. G. U., Ser. C, No. 401.

Mehnert, K. R., 1959: Der gegenwärtige Stand des Granitproblems. Fortschr. der Min., 37, p. 117—206.

Pettijohn, F. J., 1957: Sedimentary rocks. Sec. ed., New York.

Platan, H. von, see Winkler.

Ramberg, H., 1952: The origin of metamorphic and metasomatic rocks. Chicago and London.

— 1955: Natural and experimental boudinage and pinch- and swell structures. Journ. Geology, 63, p. 512—526.

— 1956: Pegmatites in West Greenland. Geol. Soc. America Bull., 67, p. 185—214.

Read, H. H., 1957: The granite controversy. London.

Reitan, P., 1956: Pegmatite veins and the surroundings rocks. I. Petrography and structure. Norsk geol. tidskr., 36, p. 213—239.

— 1958: Pegmatite veins and the surrounding rocks. II. Changes in the olivine gabbro surrounding three pegmatite veins, Risör, Norway. Norsk geol. tidskr. 38, p. 279—311.

— 1959: Pegmatite veins and the surrounding rocks. III. Structural control of small pegmatites in amphibolite, Rytterholmen, Krageröfjord, Norway. Norsk geol. tidskr. 39, p. 175—195.

REYNOLDS, D., 1954: Fluidization as a geological process, and its bearing on the problem of intrusive granites. Am. Journ. Sci., 252, p. 577—614.

SABATIER, G., see DONNAY.

TRÖGER, W. E., 1952: Tabellen zur optischen Bestimmung der gesteinsbildenden Minerale. Stuttgart.

WALTON, M., 1955: The emplacement of "granite". Am. Journ. Sci., 253, p. 1—18.

WEGMANN, E., 1953: Ueber gleichzeitige Bewegungsbilder verschiedener Stockwerke. Geol. Rundschau, 41, p. 21—33.

— 1955: Lebende Tektonik. Eine Übersicht. Geol. Rundschau, 43, p. 4—34.

— 1956: Stockwerktektonik und Modelle von Gesteinsdifferentiation. Geotekt. Symp. Stille, p. 3—19.

— 1958: Das Erbe Werners und Huttons. Geologie, 7, p. 531—559.

WINKLER, H. G. F., 1957: Experimentelle Gesteinsmetamorphose I. Hydrothermale Metamorphose karbonatfreier Tone. Geochim. et Cosmochim. Acta, 13, p. 42—69.

WINKLER, H. G. F., und PLATAN, H. VON, 1958: Experimentelle Gesteinsmetamorphose II. Bildung von anatektischen granitischen Smelzen bei Metamorphose von NaCl-führenden kalkfreien Tonen. Geochim. et Cosmochim. Acta, 15, p. 91—112.

WINKLER, H. G. F., 1960: Experimentelle Gesteinsmetamorphose III. Anatektischer Ultrametamorphose kalkhaltiger Tone. Geochim. et Cosmochim. Acta, 18, p. 294—316.

WYART, J., see DONNAY.

YODER, H. S., 1955: Role of Water in metamorphism (From Crust of the Earth. A Symposium). Geol. Soc. America, Spec. paper 62.

An Occurrence of Kyanite in a Pegmatite in Western Sweden

By

LARS BERGSTRÖM

The Geological-Mineralogical Department
Chalmers University of Technology
Gothenburg

ABSTRACT

Within the area of the geological map »Göteborg», a kyanite-carrying pegmatite has been found. The general geological features are broadly described. Chemical, physical and optical data and the d-values are given.

Introduction

Kyanite has previously only been found as an integral part of some quartzites from the Swedish pre-Cambrian bedrock (Sjögren 1876; Bäckström 1897). This investigation deals with kyanite occurring with quartz in a pegmatitic vein. The kyanite-pegmatite is situated 700 m. S.S.E. of the Hagen Chapel in Western Gothenburg. The pegmatite runs through a completely tectonized basic rock, now of medium-grained amphibolitic appearance. According to Lundegårdh (1958) who has described the petrology of this area, the amphibolite is of Late Gothian age, and probably of volcanic origin.

The kyanite occurs in a fissure 25 cm wide and 3 m long. The main mineral is kyanite. Quartz fills the interstices between the kyanite crystals which frequently reach the size of 15 × 3 × 1 cm. They are light blue to greenish-blue. The blue colour is distributed as irregular striae parallel to the C-axis. The kyanite is partly altered to micaceous minerals.

Method

The material used for chemical and x-ray investigations was obtained from crystals of greenish-blue colour. Impurities were removed under the microscope.

The refractive indices were determined by the immersion method. The angle of the optical axes and the angles of extinction were determined on the universal stage. All optical determinations were performed in sodium-light. The d-values were calculated from a Guinier photogram kindly taken by Dr. Vannerberg at the Department of Inorganic Chemistry, Chalmers University of Technology. The chemical analyses were carried out by Mr. G. Bergström, except for those of the alkalis, which were determined by Mr. A. Aaremäe.

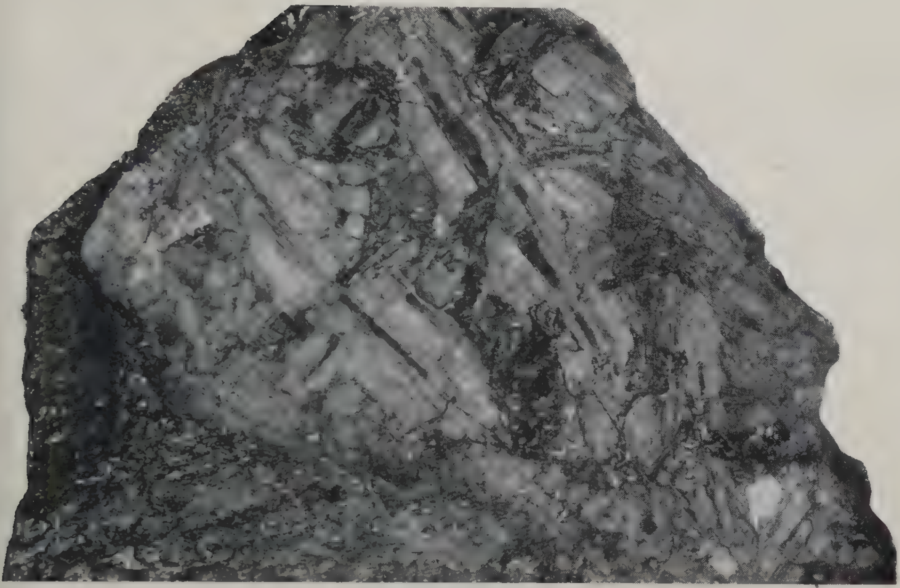


Photo: S. Dahlén

Kyanite from Hagen, Gothenburg. 0.50 ×.

The minor elements were determined by Dr. S. Landergren at the Geological Survey of Sweden.

Chemical analysis of kyanite from Hagen, Gothenburg.

	%	Mol.prop.
SiO_2	36.64	0.6098
Al_2O_3	61.65	0.6046
Fe_2O_3	0.76	0.0046
Na_2O	0.09	0.0009
K_2O	0.11	0.0011
$H_2O < 110°$	0.05	0.0025
$H_2O > 110°$	0.73	0.0405
Total	100.03	

Minor elements in kyanite from Hagen, Gothenburg.

Ni	0.002 % p.w.
Cr	0.033
Zn	0.006
Cu	0.015

Physical and optical properties of kyanite from Hagen, Gothenburg.

Colour: Light blue to bluish green
Colourless in this section
Cleavage: Perfect on (100)
Good on (010) and (001)
Extinction angles on: (100) $C - \gamma = 30° \pm 1°$
(010) $C - \gamma = 7° \pm 1°$
(001) $A - \alpha = 2° \pm 1°$
Optical angle: $2V\alpha = 82° \pm 2°$

Index of refraction: $n_\alpha = 1.715 \pm 0.001$
$n_\beta = 1.721 \pm 0.002$
$n_\gamma = 1.729 \pm 0.002$
Specific gravity: 3.67 (20° C)

Guinier photogram of kyanite from Hagen, Gothenburg.

Cu K_α radiation $\lambda = 1.54178$ Å

$\sin^2\theta$	dÅ	Intensity	$\sin^2\theta$	dÅ	Intensity
0.0322	4.29	m	0.1211	2.21	vw
0.0422	3.74	m	0.1268	2.16	vw
0.0530	3.35	m	0.1542	1.96	s
0.0586	3.18	vs	0.1598	1.93	vw
0.0653	3.02	vw	0.1899	1.77	vw
0.0682	2.95	vw	0.2337	1.60	m
0.0815	2.70	vw	0.2621	1.51	w
0.0871	2.61	vw	0.2718	1.48	w
0.0941	2.51	m	0.3052	1.40	m
0.1072	2.36	m	0.3125	1.37	vs
0.1151	2.27	vw	0.3297	1.36	vw
0.1190	2.23	vw	0.3717	1.26	m

s = strong, m = medium, w = weak, v = very

LITERATURE CITED

GFF = Geologiska Föreningens i Stockholm Förhandlingar.
SGU = Sveriges Geologiska Undersökning (The Geological Survey of Sweden).

Bäckström, H., 1897: Vestanåfältet. SGU, C 168.
Lundegårdh, P. H., 1958: Göteborgstraktens berggrund. English Summary. SGU, C 553.
Sjögren, A., 1876: Om Hållsjöberget. GFF 3.

MEDDELANDE

från

SVENSKA FÖRENINGEN FÖR LERFORSKNING

Reports from The Swedish Society for Clay Research

Nr 13

Maj 1960

INNEHÅLL

Sid.
Andersson, L.: Clay chemistry in soil stabilization 274
Höstmötet 1959 298

Föreningens ändamål är att främja intresset för vetenskaplig utforskning av lerornas egenskaper och att sammanföra för detta syfte intresserade personer till föredrag och diskussioner angående gemensamma problem.

Inträde i föreningen kan vinnas av varje svensk person, som sysslar med lerforskning. Anmälan om inträde kan göras till någon av styrelsens medlemmar. Styrelsen må även efter därom gjord anmälan bevilja medlemskap åt utländsk forskare, som arbetar i överensstämmelse med föreningens syfte.

Medlemsavgiften är kr 10:— per år och kan inbetalas på postgiro 39 02 17, Svenska Föreningen för Lerforskning, Tegellab., Stockholm Ö.

Till sekreteraren kan lämnas uppgifter om namn- och adressförändringar.

Styrelsen har följande sammansättning,

Ordförande: Laborator Bengt Collini, Inst. f. marklära, Lantbrukshögskolan, Uppsala 7.

Sekreterare: Agr. Erik Lotse, Inst. f. marklära, Lantbrukshögskolan, Uppsala 7.

Kassaförvaltare: Assistent Åke Eklind, Tegellab., IVA:s Försöksstation, Stockholm Ö.

Övriga ledamöter: Fil. lic. Ann Marie Asklund, Sveriges Geol. Unders., Stockholm 50, byråing. A. H. Hellgren, Stockholms Stads Gatukontor, Stockholm 8 samt som suppleant fil. kand. Sven Fredén, Statens väginstitut, Stockholm Ö.

Clay Chemistry in Soil Stabilization

By

LENNART ANDERSSON

CONTENTS

	Page
Introduction	274
Classification of soils	277
Constitution and properties of clay minerals	279
Clay chemical reactions when stabilizing	284
Properties of stabilized soils	292
Conclusion	296
References	297

Introduction

The term "soil stabilization", employed broadly, means every alteration to or treatment of soil designed to improve its properties in the light of the use for which it is intended (1). As regards material for roads and other civil engineering projects improvements are sought in the load-carrying capacity, frost-resistance, compactibility, water resistance etc. To a more restricted extent soil stabilization has also been interpreted in recent years as meaning such improvements of the property of the soil as may be achieved on the site by the use of certain additives which have the capacity of changing the structure of a soil. Interpreted in the latter sense soil stabilization is a new addition to earlier working methods.

The development of modern soil stabilization methods was initiated about 25 years ago, mainly in the USA. During the past decade these methods have been taken into increased use in many countries in conjunction with the building of roads, aerodromes, parking lots etc. They are employed as a complement to conventional building methods and as a substitute for both permanent and temporary jobs. Quite naturally, development in the field of soil stabilization has progressed most in the major industrial countries where the volume of motor traffic is greatest. In the case of Sweden too, where the density of motor vehicles per capita is among the highest in Europe — even though the number of vehicles per kilometre road is not particularly large — investigations and field trials have been carried out with a view applying foreign experience to Swedish conditions and soils. An item of special interest in Sweden is the effect of the cold climate on various stabilization methods. The materials which, from a technical aspect and, in particular, the financial aspect, have proved suitable abroad are bituminous additives, which are also the oldest, portland cement and lime. In addition to these compounds many others have been tried, too. However, for various reasons they have not been generally adopted. Figs. 1 and 2 illustrate in diagram form the rapid development in the USA in terms of the areas stabilized with cement and lime every year. Expressed in terms of quantity the work carried out in 1958 corresponds to more than half a million tons of cement and about a quarter million tons of lime. The trend in Germany is similar and the annual consumption of stabilizer is in the region of 100,000 tons. Major projects have been carried out in Great Britain and Russia, for example, and stabili-

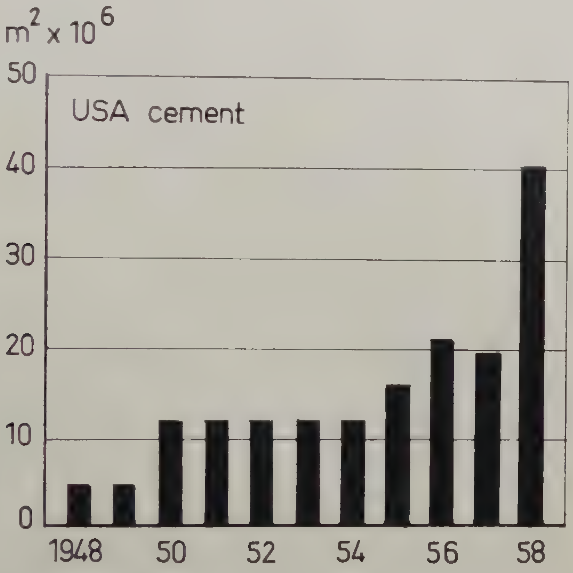


Fig 1. Development of cement stabilization in the USA (with acknowledgements to Svenska Cementföreningen).

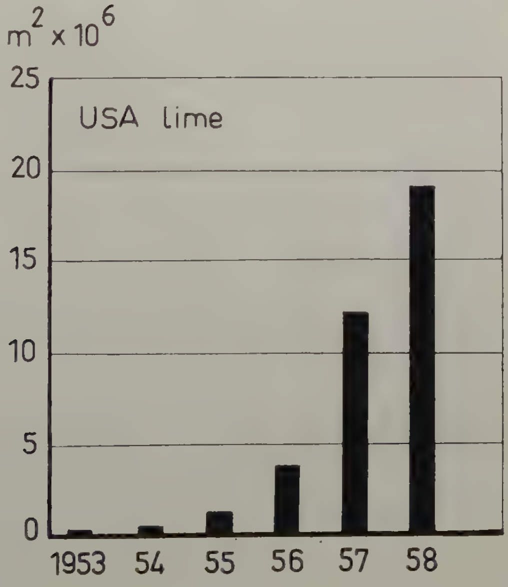


Fig 2. Development of lime stabilization in the USA (according to National Lime Association, Washington D.C.)

zation work and research in this field is being carried out in most European countries.

It is easy to understand the great interest displayed in various stabilization methods when we turn our thoughts to the exceptionally high cost involved in the construction of modern roads and runways. Every reduction in cost and every simplification of working methods quickly leads to major savings. Stabilization has been shown to be an excellent method of achieving these aims and, at the same time, maintaining or even improving the standard of the project at a cost which would be difficult to achieve via the application of conventional building methods. The rapidly increasing volume of motor traffic, speeds and weight means that demands as to the stability and constructional efficiency of roads are becoming stricter than ever before. This development is allied with the current change in social structure occasioned by the growth of motorism and the fact that more and more transportation is being effected via heavy road vehicles. Development is taking place at a rapid rate and experience from every big industrial country shows that the cost of modern roads is rising rapidly. The construction of special roads for rapid and heavy motor traffic is now the theme as compared with the older method of building roads designed to accomodate all categories of traffic. In terms of straightness, camber and curve construction these motorways far exceed previous standards. But these new roads are expensive — betwen Kr. 2—5 million per kilometre.

The economic advantages of stabilization are that a poor material can be converted into a better material on the spot and that there is no need to transport fresh material to the site. This means that smaller quantities of material need be excavated and carted away, less material need be brought to the site and consequently less transport is required. The cheapest way of building a road is to ensure that the material removed just suffices to fill in the low levels. In that no excavations are necessary below the balance level and that the bankings can be filled to the full height great savings are effected by the process of stabilizing otherwise unsuitable material. Further major savings can be effected by the need for less gravel — a factor which is also of great interest from the point of view of nature conservation. In addition to these direct savings it is also generally possible to effect economies as a result of less loss of time, especially in wet weather. Working conditions are improved and there is less maintenance on machinery etc. These indirect advantages often justify the stabilization of transport routes, even in cases where, from the purely technical aspect, such measures are not strictly necessary. An example of the economic advantages of stabilization is illustrated by the construction of the new airfield at Jönköping. The bearing layers for the runways will be stabilized and, in this way, it is expected that a saving of more than 10 % will be effected as compared with traditional building methods. The main roads at the big RILA exhibition held at Jönköping in the summer of 1959 were stabilized. This resulted in a reduction in cost of more than 15 %. As an example of the great improvement and, at the same time, major saving involved we now have oiled gravel roads — a construction far superior to the old gravel roads.

Classification of Soils

Soils are polydisperse systems — the composition of which differs from place to place — consisting of solid mineral particles, particles of organic material, ground liquids and salts and gases dissolved in these liquids. When classifying the solid mineral particles it is general to use the now international Atterberg system based on the grain size.

Grain group	Diameter in mm
Boulder	> 200
Stone	200 —20
Gravel	20 — 2
Coarse Sand	2 — 0.2
Fine Sand	0.2 — 0.02
Silt	0.02 — 0.002
Clay	< 0.002

This scale is very suitable for Swedish conditions and for the most usual type of soil, till, which covers most of the land area. Soils are seldom well sorted and consequently the designations are generally a combination of different grain group classes. As regards stabilization, however, there may be advantages in classifying the soils into friction soils or granular soils and cohesion soils. This classification is based on the quantity of material of grain size < 0.06 mm and on the basis that the fine-grain fraction is the basis of the cohesion and water-retaining properties of a soil.

Designation	Quantity < 0.06 mm
Granular soil	0— 20 %
Cohesive granular soil	20— 35 %
Cohesion soil	35—100 %

Grains coarser than 0.06 mm can generally be seen with the naked eye, from this figure down to 0.002 mm with a microscope and finer grades with an electron-microscope. The coarser grains are crushings of the parent rock forming the soil and consequently have the same mineral composition. As the size decreases the grains are divided into primary particles and the decomposible mineral is converted. As a rule the clay fraction consists mainly of primary particles and decomposition products of the original mineral. The shape and appearance of the grains are changed during the process of decomposition. The finest grains have a large active surface, with consequent electric charge and adsorption capacity and more or less marked colloidal properties. The adsorption capacity is especially marked in the case of the so-called clay minerals and the quantity of these minerals and their adsorbed ions dominates the properties of the clay fraction.

A characteristic of the granular soils is that they can easily be divided into individual grains with the aid of tools and that they are relatively insensitive to water. As a rule the grains are not bonded to one another but they can be packed to form a bearing skeleton, the strength of which depends upon the division of the grains and their shape and the actual strength of the mineral grains. To achieve greater adhesion the grains must be bonded with a binder of some kind. Depending upon their quantity and properties the finer components of the soil may provide such a binder. When stabilizing a friction soil we can either add a material with good bonding properties or increase this effect in the naturally occurring binder fraction. There may be occasions when the best results are obtained both by additives and by improving the grain distribution by adding material which fills in the empty spaces. Stabilization of a granular soil can be effected with cement or bituminous binders which, in themselves, have good bonding properties, and with or without grain improvement. Stabilization of a granular soil can also be effected by the addition of a very fine-grained soil, a clay or a so-called puzzolan, for example fly-ash, coal dust ash. The bonding capacity of the clay or the puzzolan is increased by stabilizing with lime

Cohesion soils always consist of aggregates of fine particles even after mechanical processing. The individual aggregates are bonded by the finest particles and coarser particles, such as gravel, sand or silt are enclosed. In the dry matter state a cohesion soil generally has a sufficiently high shear strength to bear traffic loads. When wet the properties of a cohesion soil differ greatly from those of a granular soil, since the latter allow water to permeate without any effect on the load-carrying capacity. The coarser particles of the cohesion soils have the capacity to retain or adsorb water by capillary attraction. In addition, the particles of the clay fraction surround themselves with a film of water which is adsorptionally bonded to the surface of the grain. Cohesion soils are affected by moisture to a far greater extent than granular soils. The shear strength decreases to zero, the soil swells appreciably, the consistency is changed and, in extreme cases, it can be transformed from a solid or plastic state to a liquid state. In this condition the soil can permeate granular soils used for the upper layers and cause considerable damage to the base of the road. This is especially serious when frost melting takes place, when the accumulation of water under the frost period is appreciable and the frost melting process takes place quickly. When a cohesion soil dries the change in consistency is in the opposite direction and shrinkage cracks may occur. Underlying, looser earth may then creep up through the cracks. The cracks may be transplanted to the upper base layers and the road consequently damaged.

When stabilizing a cohesion soil the problems are different from those connected with granular soils. The problem is not to bond the primary particles but to treat the aggregates in the cohesion soil physically so that a suitable decomposition and size of the aggregates is obtained and, at the same time, so that these aggregates are made as water-resistant as possible and bonded together so as to obtain a good strength factor. By increasing the water-resistance we can avoid the detrimental effects of the soil becoming wet and maintain the strength when wet at a level sufficiently high to allow the soil to be used for the engineering project in question. The necessary division into small pieces during the stabilization process must be carried out when the soil is suitably moist to avoid the need for excessive decomposition work. The best water content is that corresponding to the optimum Proctor water content, which is almost the same as the plasticity limit according to Atterberg. The water content prior to stabilization is often higher and consequently it may be difficult to break up the pieces mechanically, especially when dealing with stiff clays. Thus, a property of the stabilization medium must be that it facilitates decomposition so that, after treatment, the bulk of the grains are less than 5 mm. Since it will always be a case of dealing with aggregates of fine grains the stabilizing medium will operate from the surface of the soil particles. For this reason it is necessary that the water content is sufficient to allow the development of the chemical action of the stabilizing medium and to permit the medium to permeate into the pieces via cracks and pores.

Constitution and Properties of Clay Minerals

The dominant importance of the clay fraction in most soils is due to the fact that this fraction contains completely different minerals from those in the coarser fractions and that these clay minerals are small. Throughout the size range running from tens of millimetres down to about 0.002 mm the grains have consisted — chemically, that is — of largely the same minerals even though some have been divided into monomineral particles. True, the clay fraction also contains primary minerals but the bulk consists of clay minerals with completely different chemical and physical properties from those of the coarser grains or the minerals from which they have been formed. To a great extent the grains of the clay fraction are within the colloidal range (< 0.0002 mm). With such small grain sizes as these the total area of the particles is very large. This can be illustrated by the following example. A cube with 1 cm sides has an area of 6 cm^2. If we divide the cube into smaller cubes the total area at a side length of 0.001 mm will be 6 m^2 and, if the lower limit for colloidal particles is set at 0.000005 mm the area of 1 cm^3 is 3,300 m^2. This enormously large area as related to the volume of the particles results in their having specially marked properties, i.e., all properties dependent on the surface will be very evident, the adsorption capacity is considerable. Typical colloidal properties such as sol-gel conversion, thixotropy, flocculation or coagulation, peptization and hydratation are also typical properties of clays. In order to simplify the description of the properties of clays it is necessary to investigate to some extent the composition of the clay minerals. The lattice of clay minerals consists of layers. They consist of several layers of silicon dioxide tetrahedra and aluminium or magnesium octahedra which may be combined in different ways and thus give rise to different minerals (see fig. 3, as per Hauser) (2). In normal cases a lattice is always electrically neutral, with the possible exception of fracture surfaces where there are unsatisfied valency bonds. In many clays we find minerals in which lattice substitution has taken place. For example, an Al^{+++} ion may have been replaced by an Mg^{++} ion in an octahedra resulting in a deficit of positive charge, i.e., the particle has become negatively charged. In the same way Si^{++++}

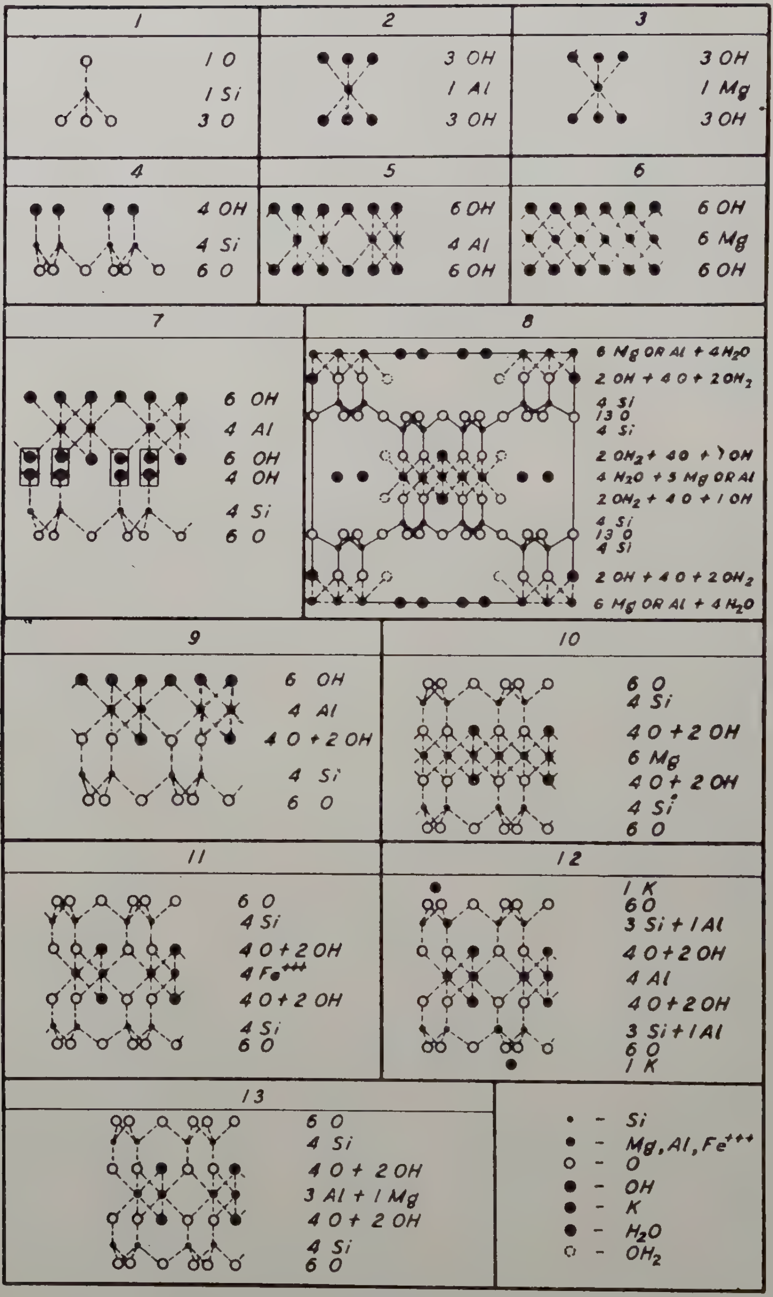


Fig 3. Structural data for the most important clay minerals and their building units (after Hauser) (2).

1 = silicon tetrahedron; 2 = aluminum octahedron; 3 = magnesium octahedron; 4 = hydrated silica; 5 = gibbsite; 6 = brucite; 7 = halloysite; 8 = attapulgite; 9 = kaolinite; 10 = talc; 11 = nontronite; 12 = mica (illite); 13 = montmorillonite (substituted).

may be replaced by Al^{+++} in silicon dioxide tetrahedra. The negative charge thus received by the particle must be compensated in some way so as to render the particle electrically neutral. This can happen by the process of its adsorbing at the surface an equivalent quantity of particles with an opposite charge, cations, such as K^+, Ca^{++}, H^+ etc.

When suspended in water the clay minerals become surrounded by a layer of oriented water molecules which are gradually transferred to the surrounding water solution. The ions required to compensate the negative charge of the particles now appear in this layer of water and in the solution. They are now called counter ions to the particle. Their negative charge is also increased in the water suspension as a result of the ionization of the hydroxyl groups in the clay mineral. Positive charges arising as the result of unsatisfied valencies may also adsorb negative ions. However, this adsorption is generally negligible compared with the adsorption of cations. The particles have a negative net charge and appear as an acid, they are acidoid in character. A particle with its layer of water and counter ions constitute a unit. The counter ions can move in the water solution and may be exchanged for ions further out in the solution. There is certain balance between the ions which belong to the particle and those which can move freely in the solution. The ions in the water solution are hydratized and become surrounded with water dipoles. Thus their actual diameter is greater than that of the ion.

The most important property of a clay colloid is its ion-exchange capacity and the consequences resulting from the fact that ion exchange is of great importance in the stabilization process. If cations of a type different from those adsorbed are added to the outer solution an exchange reaction can take place and the new type of ion can permeate the clay complex and expel some of the ions already there, these latter being dispersed into the outer solution. Exchange is controlled by the following lyotropic series where an ion on the right expels one on the left: Li^+ Na^+ K^+ H^+ (H_3O^+) Mg^{2+} $Ca^{2+}Ba^{2+}$ (the designation H^+ is used for the sake of brevity). The counter ions in Swedish clays generally consist of about 50/80 % Ca, Mg, K and Na while the remainder is made up of H-ions. If a surplus of Ca ions is added to the outer solution they will displace all the H, Mg, K and Na ions and consequently the clay will become Ca saturated. This chemical reaction takes place in reverse power to the activity of the various ions and can be described by the following reaction formula, in which L is a clay particle:

$$L - H_2 + Ca^{2+} \longrightarrow L - Ca + 2\,H^+$$

or

$$L - H_2 + Ca(OH)_2 \longrightarrow L - Ca + 2\,H_2O$$

An exchange in the opposite direction can be achieved by a precipitation reaction, for example:

$$L - Ca + Na_2CO_3 \longrightarrow L - Na_2 + \underset{\text{precipitation}}{\underline{CaCO_3}}$$

or

$$L - Ca_2 + \underset{\text{Active Silicon dioxide}}{Si(OH)_4} \longrightarrow L - H_4 + Ca_2SiO_4$$

By drenching the soil with a salt solution or with water we can bring about an ion exchange which may go in the opposite direction to the lyotropic series referred to above. The balance which always exists between the quantity of the adsorbed ions and the quantity of the same type of ions in the outer solution may be disturbed in that the ions in the outer solution are constantly removed. They are then replaced by ions from the inner solution and these, in their turn, are replaced by ions from the liquid with which the soil is drenched. If the suspension is heavily diluted this "washing-out" effect may also be characterised by changed physical properties resulting from the changed adsorption conditions.

Ion exchange in a clay suspension is generally succeeded by marked physical changes. The consistency of a clay at a given water content is governed by the electrical potential within and around the particle complex. In addition to the thermodynamic potential resulting from the charge on the particles there is also another potential, the so-called zeta potential, the size of which depends upon the outer conditions around the particle complex. The thermodynamic potential is not affected by these conditions. The reaction between these two potentials controls conditions in the suspension. The particle complex, with its film of water and counter ions, can be regarded as a capacitor with a potential (z) depending upon the charge on the particles, the thickness of the film of water and its dielectric constant and the ion concentration. In that many variables can influence the magnitude of the zeta potential very complicated conditions may arise. Changes in the consistency may pass through several maximum and minimum stages. If the zeta potential is high the particle will be highly hydratized; more water surrounds every particle. The clay suspension is stable and the consistency is that of a sol. If the zeta potential is low the water film surrounding the particles is less, they can come closer to each other until direct contact is established. The clay coagulates to a gel. The viscosity rises appreciably and the consistency changes from liquid to plastic or solid, depending on the water content. The water which has become separated from the particles is now in the cavities between the coagulated particles forming the aggregate. When ions are added to a suspension the zeta potential is changed depending upon the valency of the ions and their concentration and the pH value of the solution. However, the various ions do not have the same bonding strength or adsorption energy, these factors varying with the hydratation factor and decreasing in accordance with the same lyotropic series as indicated above (see fig. 4 after Hauser). Upon the adsorption of monovalent ions, such as K^+ and Na^+, the maximum and minimum limits for the consistency changes are especially marked. When a small addition of ions is made the zeta potential increases and a weak increase in the viscosity is noted as a result of the increased hydratization of the particles. When the zeta potential has reached maximum an increased ion additive results in a marked reduction in viscosity owing to the dispersion or peptizing effect resulting from the marked hydratization of the particles. The viscosity reaches a minimum and the particles seem to be surrounded by a film of water. Ceramic casting slips work within this area (3).

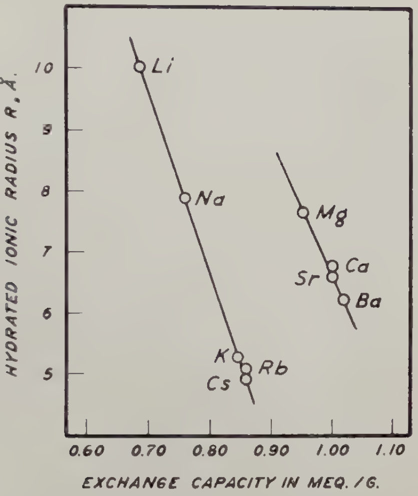


Fig 4. The radii of hydrated ions versus exhange capacity at equilibrium.

Further additions again increase the viscosity in that the zeta potential decreases and the film of water around the actual particles is reduced. Flocculation or coagulation takes place at sufficiently high ion concentration. If, under such conditions, a coagulated suspension is heavily diluted the ion concentration may be again reduced by the dilution. The "washing-out" effect will become apparent and the zeta potential increases once more. In this way the solution can be repeptized and the viscosity will again fall. This action is probably of importance with regard to frost melting in soils coated with monovalent alkali ions. In the case of divalent ions, such as Ca^{2+}, which only have a weak peptization capacity at low concentrations -- but a marked flocculation effect at high concentration — there is no maximum zeta potential. Thus the addition of a large surplus of lime to a clay results in marked coagulation and the consistency stiffens to a considerable extent. The risk of repeptization as a result of heavy dilution is also reduced owing to the surplus of Ca ions and to the slight peptization effect of these ions at low concentrations.

Owing to the low zeta potential of the particles and the slight peptization capacity of the Ca ions a coagulated clay with a surplus of Ca ions is far less affected by water than a clay with monovalent counter ions such as Na^+ or K^+. If a clay coagulated with Ca ions is saturated with water the cavities will be filled in the same way as in the case of capillary attraction while the coagulated particle aggregates are only effected slowly. In the case of a clay which has not been treated with Ca ions -- in which the counter ions often consist largely of monovalent ions — the particles can build up a film of water corresponding to the higher zeta potential or to the higher dispersion capacity of the adsorbed ions as compared with the Ca ions. The clay swells more than the Ca-ion saturated clay, which former may often be self-disintegrated in water. Swelling with the adsorption of water and shrinkage when water is removed are two properties which are influenced by the adsorption conditions of the clay.

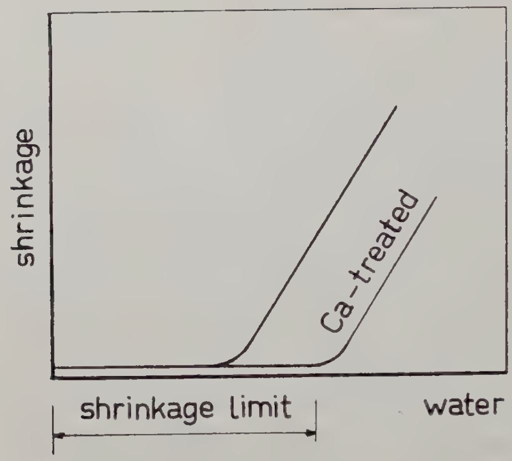


Fig 5. Shrinkage curves for untreated and lime treated clay.

Both these properties are of great importance to road builders. A clay coagulated with Ca-ions will adsorb more water in the capillaries between the particle aggregates before swelling takes place than is the case with a non-coagulated clay in which swelling takes place at a more rapid rate. For this reason the water content at maximum density is, according to Proctor, higher for a coagulated clay than for a non-coagulated. The swelling and skrinkage processes are shown in fig. 5. Generally speaking there is less shrinkage in a Ca clay than in a clay with monovalent ions. A Ca clay also dries quicker as a rule. The strength of a dry Ca clay is less than that of a Na clay, for example. For this reason the addition of lime facilitates drying and powdering. In practice this has been found especially useful when dealing with stiff, moist soils in that the mechanical handling of these soils can be greatly facilitated by lime stabilization. Vehicles will be able to advance over such soils with far greater ease — a factor of great economic importance, especially during wet weather.

Clay Chemical Reactions when Stabilizing

Many soils have a grain distribution and clay mineral content of such character that chemical reactions may take place between the stabilizer and the clay fraction. As a rule these reactions are most marked in cohesion soils, while soils with a smaller content of fine-grained material, cohesive-granular soils and friction or granular soils are less affected by chemical conditions in the fine fraction; this influence varying with the composition. Using the normal nomenclature the range varies from stiff (A 6) to light clay (A 4) or sandy soils and till with a clay content. As regards the most usual stabilizers referred to earlier not only lime, but also cement, can give rise to chemical reaction between the lime hydrate and the clay since, during the hardening stage, cement forms a small amount of lime hydrate.

The reactions between a clay and the Ca ions from the hydrate are of two distinct types; those which take place immediately after the addition of the Ca ions and those which take place over a longer period of time, long-term reactions. The former, which were dealt with in the preceding section, are purely colloidal in nature and result in a physical conversion of the structure of the clay. The latter take place much more slowly and over a long period of time and result in the establishment of new chemical compounds or minerals. Whereas the first reactions take place within the course of seconds and minutes the latter take weeks and months. These second reactions are often called puzzolan reactions and materials which have the capacity to react with lime and give rise to new minerals of the type encountered when cement hardens are called puzzolans after a volcanic rock of this name found in Italy. Puzzolans consisting of volcanic, glassy rocks are very effective. As a rule puzzolan effect in soil is connected with the occurrence of active silicon dioxide, which often occurs in soils in hot climates. Even ordinary clay has these properties to some extent.

CHANGES IN CONSISTENCY

The first effects of the additives are on the consistency of the clay. Upon the addition of Ca ions the clay coagulates immediately and the shearing strength and resistance to water are raised. The changes in consistency can be followed in several ways, for example by determining the Atterberg limits. In the USA these are often used as a simple guide to the suitability of the soil vis-à-vis one stabilization method or another. This simple method has not been found suitable in Sweden, where the choice of type and quantity of stabilizer is based on methods which improve the strength properties. However, Atterberg's limits are used when classifying soils.

The addition of lime has a very marked effect on these limits. Table 1 and fig. 6 show the changes in the limits for various Swedish clays with increased additions of lime. As will be seen the plasticity limit is generally altered to a

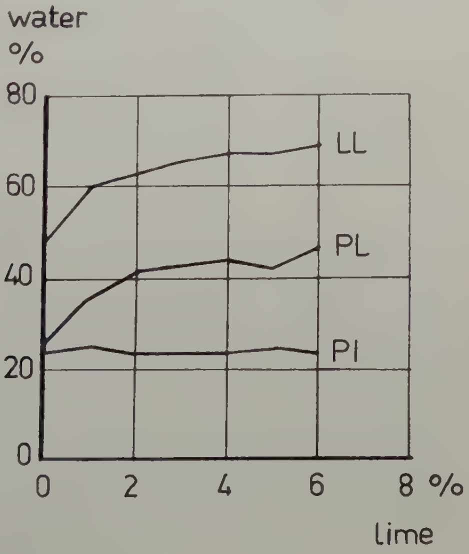


Fig 6. Change in Atterberg limits in a stiff medium clay from Sala when stabilizing with lime.

great degree while the change in the liquid limit is sometimes less pronounced and sometimes equally pronounced. The difference, PI, a decrease in which is considered very important in the USA, is sometimes unchanged, sometimes lower and sometimes higher with these clays.

A good indication of the changes, which allows also for the actual water content of the clay, can be obtained by studying the so-called consistency factor. According to Atterberg's limits the consistency factor (k) follows the formula

$$k = \frac{W_1 - W_n}{PI}$$

where W_1 = liquid limit
W_n = natural water content of the soil
PI = plasticity index

The following ranges are obtained

k = >1 solid
0 — 1 plastic
<0 fluid

Of course, the boundaries between these states are not precise.

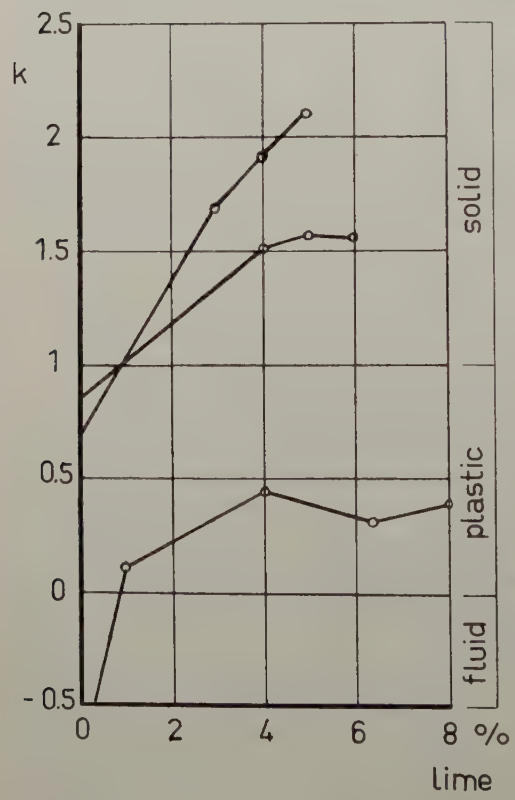


Fig 7. Change in consistency (k-value) on adding lime hydrate.

Fig. 7 shows the increase in the consistency factor in various clays with increased additions of lime. The changes are very pronounced, at times to the extent that a change in the state of aggregation takes place. The clay samples were taken from various depths below cultivated ground, i.e., from the dry crust or the subsoil and from deeper layers. Their base exchange capacity and ion coverage in the natural state and also the base saturation are normal. Ca ions result in a marked change in base and consequent coagulation. The Ca ion has, after all, the greatest flocculation effect of all the ions normally present in the ground. In this connection it may be mentioned that, in addition to cement and lime other preparations containing Ca ions have also been used, e.g., Ca acrylate, which has been patented in the USA. This preparation results in both coagulation and bonding. The effect of $CaCl_2$ is well known. For various reasons neither these nor several other preparations have been used in conjunction with stabilization.

A complete change of base in these clays would mean the consumption of about 0.75 % $Ca(OH)_2$ if the average base exchange capacity of the clays can be considered to be about 20 me per 100 grammes, which is a quite usual value. As will have been noticed from the diagrams the general practice is to add at least 5—6 times as much lime, i.e., a considerable surplus. This raises the pH value and consequently the acidic properties of the clays become even more pronounced. As a result of the large surplus of lime it is ensured that the ion concentration is always sufficiently high to bring about complete coagulation. A further contributory factor is that the quantity of liquid in the ground is small. As a rule stabilization is used when the water content is at, or slightly above, the plasticity limit.

One of the aims of chemical conversion of clays in the manner indicated above is to permit mechanical stabilization, i.e., compaction by means of rolling. The water content of clays which is of particular interest in this connection is the optimum water content for best compaction as determined in the Proctor apparatus. Stabilization should be carried out at this water content or within 95—100 % of this figure, but not at an appreciably higher value since the plastic properties of the clays rise quickly with increased water content. This may lead to plastic deformations and harder going for machines and vehicles. The optimum Proctor water content is influenced by the coagulation. Fig. 8 shows a number of curves applicable to a German loess soil. As will be seen the water content rises considerably with the addition of lime. The maximum density is also reduced slightly and the pore volume is greatly diminished. The Germans have taken advantage of this factor when constructing the north—south autobahn (4). The loess soil in question had a natural water content which was often about 10 % higher that that corresponding to the optimum Proctor density and consequently the soil was almost half-fluid. By coagulating the soil with lime it was possible to raise the optimum water content by about 4 % (see fig. 8). By using unslaked lime, which was of course immediately slaked on laying, about 1 % of the water content was consumed. The remaining approximate 5 % was evaporated by ventilation, this taking place and being

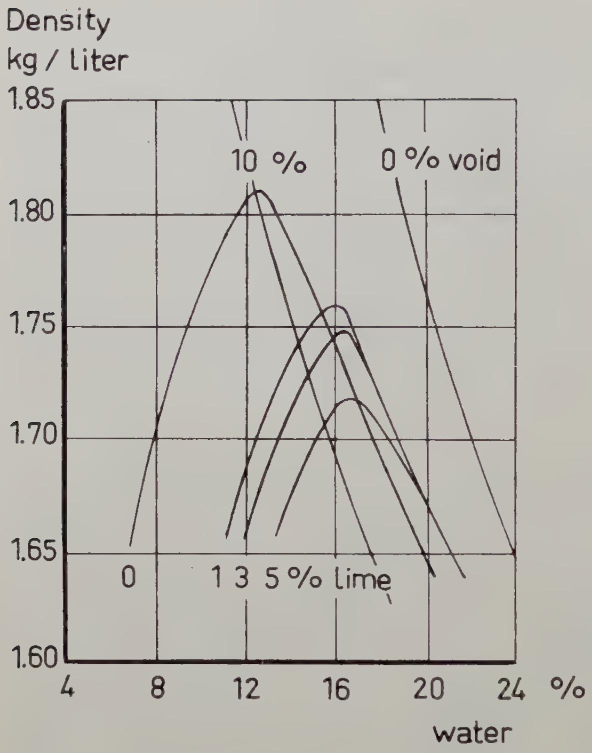


Fig 8. Density-water content curves (Proctor) for German loess soil, after Brand and Schönberg.

made possible by the lime during the mixing stage. The heat of the slaking reaction also contributed to the evaporation.

As a rule the shrinkage limit, the plasticity limit and the water content are close to each other and thus compaction takes place when the water content is such that the adsorption water film on the clay particles is fully developed and the capillaries only very slightly filled and the swelling still insignificant When in this state the clay packs tightest and consequently mechanical treatment reduces the capillary volume to a minimum. The original pore water now suffices to fill the capillaries after compaction. Fig. 8 shows how the volume of the cavities is reduced with an increased addition of lime. At the same time the water content required for maximum density has increased somewhat, this meaning that, as a result of coagulation, the consistency of the clay has stiffened so much that a certain extra additions of water is necessary in order to obtain the same maximum density with the same mechanical processing as before coagulation. This additional quantity of water corresponds to the somewhat lower maximum volume weight in the coagulated state. As a result of ion exchange during the stabilization process the resistance of the clay to disintegration by water is raised. A clay stabilized in this way is impermeable to water, but water vapour can permeate it.

The increased stiffness of the clays resulting from coagulation is accompanied by an increase in shearing strength. Fig. 9 shows a diagram of the relation be-

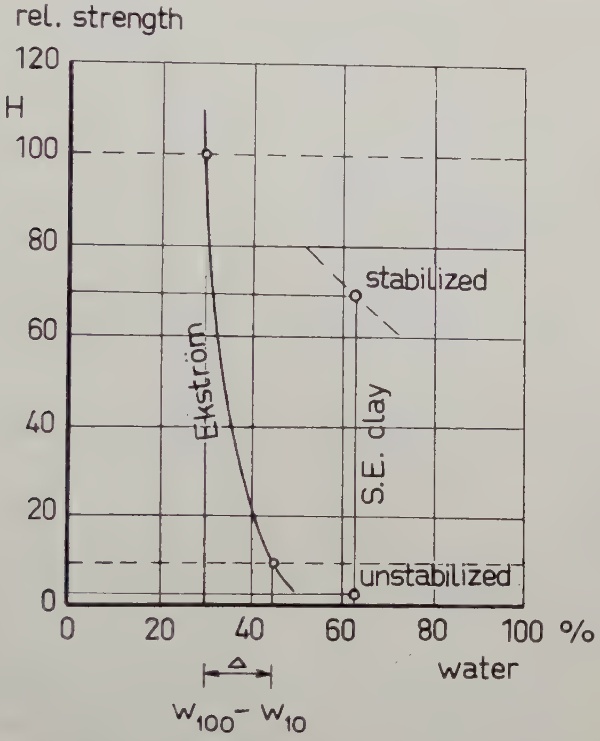


Fig 9. Effect of stabilizing with 6 % lime on Skå-Edeby clay.

tween the shearing strength and the water content with a superimposed curve indicating Ekström's (5) method of classifying clays by measuring the difference in the water content at the relative strengths of H = 10 and H = 100. The diagram also includes two points indicating the previously mentioned (Table 1) very loose clay from Skå-Edeby with and without the addition of 6 % lime hydrate. The relative strength, measured with a cone, rises from 2.9 to 69.0 and the shearing strength from 0.007 kg/cm^2 to 0.170 kg/cm^2 or about 25 times at constant water content. If Ekström's method is applied to the stabilized clay the curve should be flatter than that for the unstabilized clay with a greater difference in water content. The relation between the two differences can then be used to express the increased resistance to disintegration.

PUZZOLAN REACTIONS

Since time immemorial calcium compounds have been the most important type of bonding agent for building purposes. The use of slaked lime, which hardens by adsorbing carbon dioxide from the air, air lime, has been known for at least 5,000 years. The Romans mixed lime with volcanic rocks, puzzolans or trass and thereby obtained a bonding agent which was stronger than air lime and which would harden when wet. In modern times Portland cement, which hardens as a result of the hydratization of tri- and di-calcium silicate, has been developed. This product, and a number of simpler types, constitute hydraulic

Table 1, showing Atterberg limits for certain Swedish clays

Clay	Lime %	PL	LL	PI
Stiff clay, Sala	0	28.4	66.9	38.5
	5	55.0	91.3	36.3
Stiff medium clay, Sala I	0	20.6	42.8	22.2
	5	39.6	54.1	14.5
Stiff medium clay, Sala II	0	29.0	50.5	21.5
	3	43.4	59.3	15.9
	5	46.4	58.7	12.3
Silt clay, Avesta	0	17.2	24.8	7.6
	3	20.4	30.1	9.7
	5	20.2	33.9	13.7
	7	20.6	31.7	11.1
Sandy light clay, Jönköping	0	14.6	25.4	10.8
	5	22.0	34.5	12.5
	7	20.8	34.1	13.3
Medium clay, Dylta	0	20.3	42.0	21.7
	3	33.7	46.7	13.0
	5	35.0	43.8	8.8
Blue clay, Skå-Edeby water content 80 %	0	25.1	57.8	32.7
	4	53.2	98.0	44.8

bonding agents. When using these binders only the addition of water is required to bring them into action. The Romans' original method of mixing lime with another mineral and water is used in a modified form today when making lime-sand brick and certain lightweight concretes. The reactions between the lime and the mineral (with its high content of silicon dioxide) are accelerated by heating in an autoclave. At a temperature of around 200° C a fairly complete reaction is obtained between the lime and the mineral additive in 15—20 hours. This results in the creation of new minerals of a type similar to those formed when Portland cement hardens (6).

At ordinary outdoor temperatures the reactions between lime and ordinary soils take place far more slowly. In addition to temperature and moisture the course of the reactions depends upon the varying reaction between lime and different soil minerals. However, in the case of stabilizing, much more time is available than when producing building materials and consequently puzzolan reactions in stabilized soils are of great importance. It can be said that they prolong and improve the increase in quality obtained when changes in consistency are brought about by the exchange of ions during the course of the colloid chemical reactions. This means that the properties of stabilized soils after a certain period of time depend upon the immediate colloid chemical reactions when stabilizing and upon the changes which take place with time as a result of puzzolan reactions.

Most fine-grain soils display puzzolan properties of varying degree. Silt which contain large quantities of fine-grain silicon dioxide have a considerable reaction with lime. Stiff clays, in which the clay minerals dominate in the finest fractions, also display puzzolanic activity. Fig. 10 shows the growth in

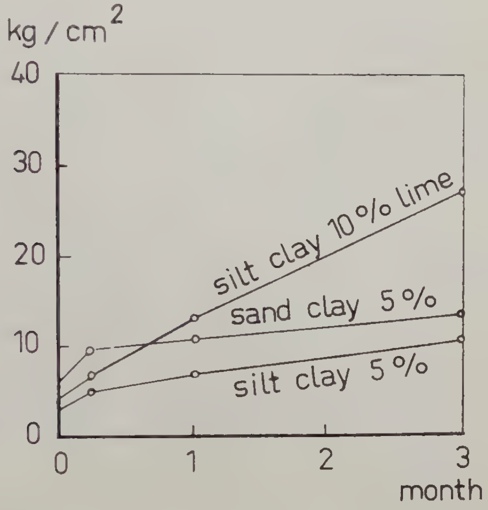


Fig 10. Effect of curing time on crushing strength.

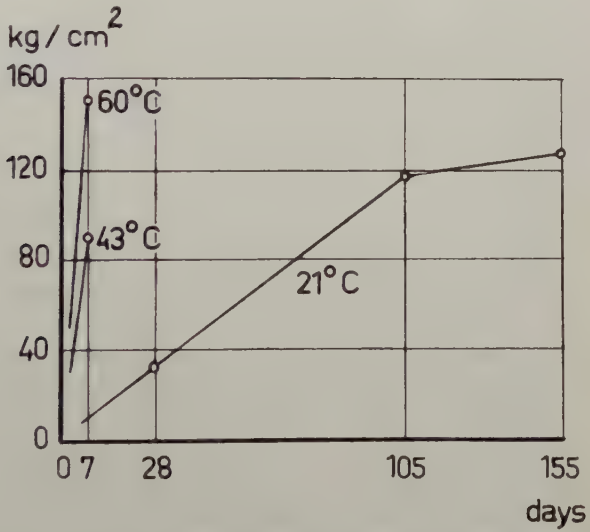


Fig 11. Effect of Curing on the Compressive Strength of Iowa loess Stabilized with Hydrated lime (after Laguros, Davidson, Handy and Chu).

strength of a silty clay and a medium clay. In order to show the dependence of the growth in strength on the temperature details are shown in fig. 11 of the curves obtained with a loess soil from Iowa (7).

In many cases, especially with poor soils, the content of mineral with adequate puzzolanic activity is too small to enable acceptable results to be obtained when stabilizing with lime. In such cases it is possible to add not only lime but also a suitable mineral with good puzzolan properties. One of the most common in the USA is fly-ash — coal dust ash. This is used on a fairly wide scale. According to a recently published investigation carried out by Leonard and Davidson (8) the prime reaction product between lime and fly ash is a gel. This gel then leads to the production of a crystalline form, probably calcium silicate I. The reactions are greatly dependent on the temperature, which should be in excess of 20° C. Another material with good puzzolan properties is trass. This was used in Roman times and is found in Germany, among other countries. It is used in the same way as fly-ash and also as a binder together with lime in so-called trass-lime concrete (9). This has been used to some extent for road-building. When stabilizing with Portland cement the strength is increased, but only the strength, and there is therefore no dependence on the puzzolan content. Thus cement is the best medium for poor and coarse-grained soils. In the case of somewhat more fine-grain soils the quantity of lime hydrate formed is often too small to bring about the desired coagulation of the clay fraction. In this case a mixture of lime and cement can be used, the lime improving the consistency and the cement acting as a binder. By the addition of lime the soil can be more easily pulverised so that it can be stabilized with cement. However, a combined process of this kind is often limited in action by other factors which influence the bonding properties of the cement, for example the humus content.

Properties of Stabilized Soils

As has been indicated earlier, the improvement of cohesion soils by stabilization is mainly a question of improving their properties when in the wet state. The demands made on the material depend to a great extent upon in which part of the road construction they are to be used. Generally speaking it can be said that the nearer the surface of the road the greater the demands as to strength and resistance to water and frost action.

The procedure adopted when determining the load-carrying capacity of a material in Sweden and Germany, among other countries, is shown in diagram form in fig. 12. Test bodies — with a water content corresponding to the optimum according to Proctor — are filled with varying quantities of stabilizer. After a certain curing, or storage, period during which the test bodies are protected from damp by a layer of paraffin wax, the crushing strength is determined on test bodies which have been saturated and drenched with water for two days and on bodies containing the original amount of water. It will be seen from fig. 12 that the strength at the Proctor water content increases immediately upon stabilization and thereafter increases considerably with time. Prior to stabilization the strength of the soaked test bodies is nil but the strength increases rapidly after stabilization and, after 7 days, is about twice as high as that of the unstabilized not soaked test bodies. The type of soil referred to in fig. 12 is a sandy light clay with about 60 % of the material finer than 0.06 mm and with an approximately 25 % clay fraction. It is a pronounced frost-heaving clay with a frost action sensibility rating of III. After a period of time longer than that referred to in the example the strength can rise to a high figure. Fig. 11, which refers to investigations carried out in Iowa, shows that the crushing strength can rise to more than 100 kg/cm^2. Trials with a silt clay from Dalarna resulted in values of about 30 kg/cm^2 after 3 months. The difference between the strength at the Proctor water content and on soaking should not be too great. A difference of about 30 % is normal.

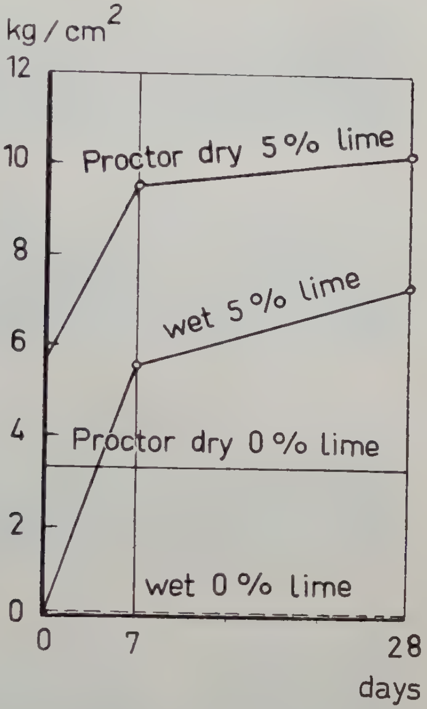


Fig 12 Effect of curing on compressive strength of a clay silt, stabilized with 5 % hydrated lime.

Other methods, too, are used to check the increase in strength and one of these is to measure the module of elasticity of the soil at various stages of saturation. This method was developed by Odemark (10) at the Swedish Road Research Institute. It is a non-spoil method and has as such certain advantages. In the USA various forms of triaxial method (11) are used and are directly related to the classification systems employed there. California bearing ratio (CBR) is another well-known method of the penetration type.

Details have already been given of the effect of stabilization on the water resistance of soils. In fig. 12 this improvement is shown as increased strength in the soaked state. The improvement is due both to the reduced sensitivity to water following changed adsorption conditions and to the increase in strength with time. Similar results have been obtained with silt clay and stiffer clays. Fig. 13 shows a series of pictures of a simple test of silt clay from southern Dalarna. The test bodies on the left have been stabilized with 5 % lime hydrate and cured during a period of 7 days. The test bodies shown on the right have not been stabilized. In the uppermost picture they are placed in their respective dishes. Water is then added to a height of 1 cm. The pictures show the state after 0.5, 2, 3, 5 and 10 minutes. The unstabilized bodies quickly become saturated and fall apart while the stabilized bodies adsorb relatively little water. During the 3 months since the test was made the stabilized test bodies have not been changed by this water treatment.

As regards resistance to freezing and thawing not a great deal of material

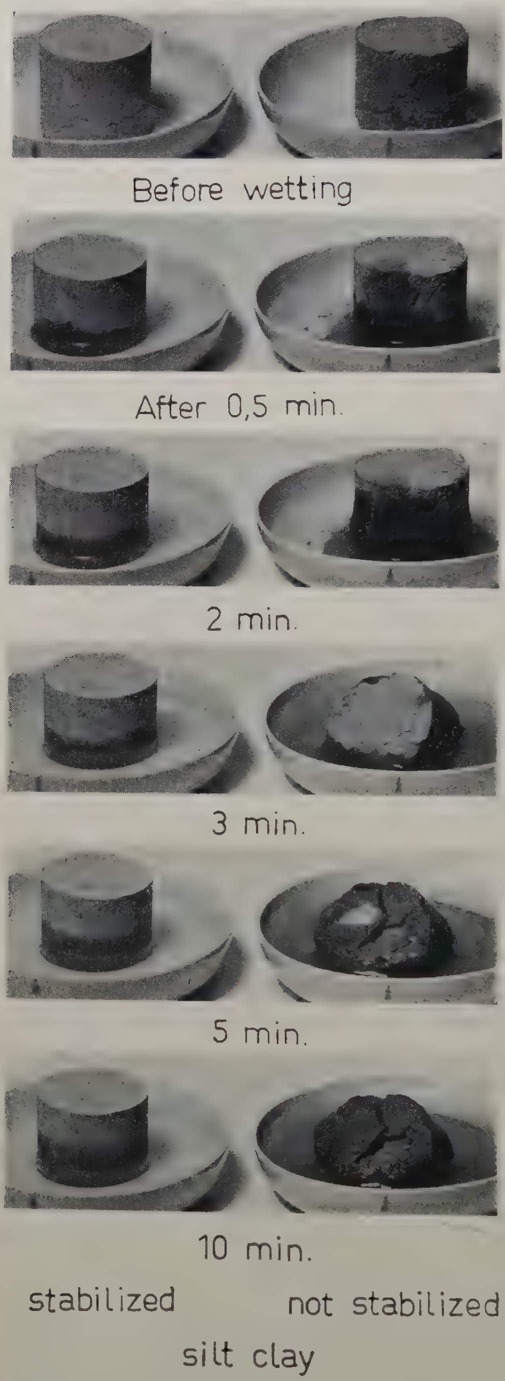


Fig 13. Comparison between stabilized and unstabilized clay silt upon adsorption of water.

is available; this being mainly due to a lack of suitable measuring methods. Methods used in other connection have been found to be less suitable for stabilized earths (7).

According to a Russian investigation (12) dealing with the lime and bitumen stabilization of a gravel-soil mixture the strength is reduced initially when subjecting the material to repeated freezing but later settles to a more or less constant value.

However, there are several good practical examples of improvements of frost action damage by stabilization (13). A small number of practical tests on a small scale have been carried out in Sweden and the results have been good. These have stimulated further tests on a large scale and laboratory trials with suitable apparatus. New results are expected but, quite naturally, such tests take time since, to be able to arrive at any definite conclusions, many instances of frost break up must be considered. Test borings have been made on a trial road constructed in the summer of 1957. These test borings were made at the end of the winter period and it was found that no water accumulation or ice-layer formations were evident in the stabilized clay, nor above it. However these phenomena were evident below the layer and this would appear to indicate that insulation against water transport from below was sufficiently good. The results may also be interpreted as indicating that the stabilized layers of clay have had a better inner strength and a smaller capillary water content than the unstabilized clay underneath. As a result the frost expansion has had less effect on the stabilized clay and the occurrence of large cavities due to cracks has been avoided. In this way no ice lenses have been able to form as a result of the intrusion of water during repeated freezing actions. It is probable that both this improvement in resistance and the reduced water-transport capacity have contribted to the good results.

The phenomena of frost action sensibility, swelling and shrinkage are closely allied to adsorption conditions in the clay fraction. As has been mentioned earlier a clay complex which has been stabilized and thus Ca-ion saturated has far less adsorption water and a reduced tendency to adsorb water and swell than is the case with a clay which has not been stabilized in this way. In that compaction takes place when the water content is such that only a small quantity of water fills the capillaries, the total capillary cavity after mechanical processing is fairly slight. The curve shown in fig. 8 shows that the cavity volume after stabilizing had been greatly decreased after compacting this lime-stabilized loess soil. The relation between the quantity of adsorbed water and the quantity of free water in the capillaries is dependent on the structure of the soil and the grain distribution. A lighter earth holds proportionally more capillary water than a stiffer one. When a clay freezes the water in the cavities and cappillaries is converted into ice and expands. The adsorption bound water is already of a structure similar to ice crystals (14) and consequently there is little or no increase in volume. The damaging action of the frozen water in the capillaries depends upon the quantity involved and the existence of cavities in the same way as when wet, porous material is frozen. When the freezing action is repeated there is the additional factor of water transport capacity; this latter generally being slight in stabilized clays. The adsorption-bound water cannot cause damage. A well compressed and coagulated clay should thus offer fairly good resistance to frost break-up, mainly because the quantity of damaging water is small. Resistance is also dependent upon the inner strength or cohesion of the material and its capacity to resist the stresses resulting from the expansion in volume of the frozen water. On thawing the volume of the water is again reduced while the capillary volume is a little larger than before freezing. As a result of consolidation the material can revert to its original volume without any great reduction in the strength. However, should the clay be prone to swelling this may happen before the material has had time to consolidate after thawing. This propensity is fairly slight in a clay stabilized with Ca ions, but a clay with monovalent ions has a far greater propensity to swelling. In unfavourable cases a rapid change in consistency, with a consequent reduction in strength, may take place as a result of the "washing-out" effect described earlier. In extreme cases the strength may be so reduced that the weight of traffic causes a break — frost break up damage.

As a rule stiff clays are less sensible to frost action than light clays, nor are very coarse-grained soils prone to frost action. The most dangerous zone is between the pronounced friction soils and the pronounced cohesion soils. In this zone there are soils with a marked capacity to retain water, mainly capillary water. The possibilities of influencing their sensitivity to frost heave by changing the adsorption conditions will then depend upon the size of the clay fractions. It should be possible in many cases to stabilize these soils with a suitable mixture of lime and a puzzolan or, in some cases, a stiff clay and thus bring about better resistance to swelling as a result of Ca ion adsorption and higher internal strength as a result of the stabilizing action. Many of the gravel roads in Sweden would probably be a suitable field for experiment.

Conclusion

Owing to their content of clay minerals cohesion soils and transition types to more coarse-grained soils are sensitive to changes in the type of ion contained in the ground water. The physical properties of soils are greatly dependent upon the ions adsorbed in the clay minerals and their concentration in the ground water. Modern stabilization methods involve the treatment of the soil with chemical additives which, by coagulating the clay mineral, result in an improvement of the engineering properties of the soil, stabilization. It is primarily a question of improving the properties of the soil in the wet state. Stabilization is the result of colloidal chemical changes and a puzzolan reaction between the lime additive and the natural puzzolan content of the soil. The puzzolan effect can sometimes be increased by the addition of suitable material. The resistance of the soil to water and frost heave can be improved by stabilization. Continued research in this field will probably be of major economic importance to development in the construction of roads.

References

1. Winterkorn, H. F., 1955: The Science of Soil Stabilization. Highway Research Board, Bull. 108.
   — Bodenstabilisierung.
   — Wasser im Boden. Tagung über Bodenstabilisierung, Nürnberg, Sept. 1958. 1959: Strassen und Tiefbau, H. 3.
2. Hauser, E. A., 1955: Soil Stabilization and Colloid Science. Highway Research Board, Bull. 108.
3. Holdridge, D. A., 1953: The Colloidal and Rheological Properties of Clay. Ceramics, A Symposium, Stoke on Trent, pp. 60—93.
4. Brand, W., and Schönberg, W., 1959: Impact of Stabilization of Loess with Quicklime on Highway Construction. Highway Research Board, Bull. 231.
5. Ekström, G., 1927: Klassifikation av Svenska åkerjordar. Sveriges Geol. Unders., C 345, Stockholm.

6 a. Assarsson, G., 1960: Hydrothermal Reactions of Calcium Hydroxide — Quartz at 120—220°. Journ. Phys. Chem., *64*, pp. 328—331.

6 b. Kalousek, G. L., 1954: The Reactions of Cement Hydration at Elevated Temperatures. Chemistry of Cement, London, p. 334.

7. Laguros, J. G., Davidson, D. T., Handy, R. L., and Chu, T. Y., 1956: Evaluation of Lime for Stabilization of Loess. A. S. T. M., Proc. *56*, pp. 1301—1315.
8. Leonard, R. J., and Davidson, D. T., 1959: Pozzolanic Reactivity Studies of Flyash. Highway Research Board, Bull. 231.
9. Kremser, H., 1958: Die mit Trasskalk vermörtelte Schotterpackung. Strassen-, Asphalt- und Tiefbau-Technik, H. 18—19.
10. Odemark, N., 1949: Investigations as to the Elastic Properties of Soils and Design of Pavement according to the Theory of Elasticity. Statens Väginstitut, Medd. 77.
11. 1954: Lime Stabilization of Roads. National Lime Association, Washington D C, Bull. 323, pp. 52—65.
12. Gelfand, S. I., 1957: Additives improving the adhesion of bitumen to gravel. Avtom. Dorogi, H. 11, pp. 22—24.
13. Sipe, J., 1956: New Mexico Road Reconstruction Project Eliminates Frost-Heaving Damages. Better Roads, Nov.

14 a. Grim, R. E., 1953: Clay Mineralogy. London, p. 162.

14 b. Forslind, E., 1952: The Clay-water System. Swedish Cement and Concrete Research Institute, Proc. no. 17.

14 c. Rosenqvist, I. Th., 1958: Remarks to the Mechanical Properties of Soil Water Systems. Geol. För. Stockholms Förhandl., *80*, p. 444.

Höstmötet 1959

Svenska föreningens för lerforskning höstmöte hölls den 16 november 1959 på Hotell Gillet i Uppsala.

Ordföranden förklarade sammanträdet öppnat och hälsade de närvarande välkomna.

Sekreteraren föredrog styrelseberättelsen.

Revisionsberättelsen upplästes av laborator K.-I. Skärblom. På förslag av revisorerna beviljades styrelsen full ansvarsfrihet för det gångna verksamhetsåret.

Årsavgiften fastställdes till kr 10: — för enskilda medlemmar och kr 200: — för korporativa medlemmar.

Styrelsen fick den sammansättning som framgår av första sidan.

Valnämnden föreslog, att ett sekreterararvode skulle utbetalas. På förslag av ordf. remitterades ärendet till styrelsen för yttrande.

Civiling. L. Andersson, Strå Kalkbruk, Stockholm, höll föredrag över ämnet: »Om jordstabilisering. Några lerkemiska aspekter». Efter föredraget visades en film om jordstabilisering med kalk. I diskussionen yttrade sig hrr T. Hagerman och G. Assarsson, fru A. M. Asklund samt föredragshållaren.

Vid den gemensamma lunchen avtackade ordföranden de avgående styrelseledamöterna lab.ch. Ch. Enberg och tekn. lic. S. T. Lundin.

Ass. Å. Eklind, Tegellaboratoriet, Stockholm, höll föredrag över ämnet: »Olika deflockuleringsmedel vid partikelfördelningsanalyser». I den efterföljande diskussionen yttrade sig hrr G. Assarsson, L. Wiklander, O. Peterson, F. Brotzen, R. Söderblom, F. Rengmark och föredragshållaren.

Laborator S. Andersson, Kungl. Lantbrukshögskolan, Uppsala, höll föredrag över ämnet: »Om kapillära stighöjder och vattenhaltsjämvikter». I diskussionen yttrade sig hrr O. Petersson, G. Assarsson, T. Hagerman och föredragshållaren.

Ordföranden tackade föredragshållarna, och mötesdeltagarna förflyttade sig till den nya mineralogisk-geologiska institutionen vid Uppsala Universitet, där prof. E. Norin inledningsvis gav en översikt över institutionens planering. Institutionen visades därefter av prof. E. Norin och lab. S. Florin.

Sammanträdet hade samlat ett 50-tal deltagare.

On the Granite and Spilitization

By

VLADI MARMO

Geol. Tutkimuslaitos, Otaniemi Finland

Introduction

In this journal, the paper of Oftedahl (1958), on the theory of exhalative-sedimentary ores, has caused issuing of additional papers written by several authors, including myself (Marmo, 1958). Thus, also Oftedahl (1959) having answered to the most of his critical reviewers, the unprejudiced readers should be able to take an attitude toward the views both of the presented theory and of its criticers. Hence, the repeated remarks of an author, who already has expressed his opinion, may appear here as entirely undue.

In his reply, however, Oftedahl (1959) touched some questions of utmost importance not only for his theory but also for the granite-ore problem, in general. To my opinion, the manner of consideration of some cited data presented by Oftedahl in his reply is unsatisfactory mainly because the works thereby cited have been generalized by him to fit a certain opinion, simultaneously neglecting the fact that these generalizations are actually against the descriptions cited. On the other hand, there the meticulous search for the ore-forming material in the granites has been carried out, at the same time entirely spurning ample other sources (sulphide schists particularly) readily available.

These observations prompted the writing of the additional remarks on the thoughts-inspiring paper of Oftedahl. I will restrict myself into problems of granite and spilitization.

What is granite?

It is entirely senseless to discuss the granite problem unless the term "granite" is properly defined. There is much difference between, say, a synkinematic granite-looking rock and a late-kinematic ideal granite; and still, in the literature, the term "granite" mainly includes everything what looks like a granite. The fact that the actual granites compose a very unimportant fraction of all the rocks termed as "granites"', has been stressed in an emphatic manner by Walton (1955), and, later on, by Marmo (1956) and Smulikowski (1958).

If a *granite* is to be interpreted as being of magmatic origin, then it must fullfil at least the following conditions:

1. It must have a true granite composition, which means that it must be rich in potassium, because otherwise the rock is not any granite.

2. The potash minerals (feldspar) in these granites must be evenly distributed, and, therefore, different parts of the same rock body must have homogeneous composition deviating but a little from the average composition of the whole granite body.

3. The distribution of potash feldspar in the rock must be such, that any *large* age differences between younger potash feldspar and other constituents of the rock there should not occur.

These conditions may be, and usually they are, fullfilled in the late- and postkinematic granites (for instance: Marmo, 1958). These granites appear in the field as true intrusive bodies, and, consequently, they *may* be of magmatic origin. Certainly, concerning the origin of these granites, there opposed views exist as well (Marmo, 1958a), but, still, they *may* be magmatic. The late- and postkinematic granites, however, do not form any really extensive and homogeneous bodies. In the overwhelmingly most cases examined they form bosses or dykes of restricted size; and, if any sulphide ore bodies are indisputably connected with some granites, the host rock is always late- or postkinematic, and comparatively small in size. The present writer has explained this fact as being due to emplacement of granites and ores (other than molybdenite and uranium) into similar tectonical environment rather than to the genetical relationship between granites and ores (Marmo, 1958b). In the present discussion, however, this statement is not of any fundamental importance, because it does not affect the actual subject here to be discussed.

The really large "granite" bodies — the batholiths, on the contrary, do not fullfil the requirements set forth in the foregoing for the magmatic *granite* bodies. Very seldom they attain the composition of granite, but mostly they are granodiorites or quartz diorites (Marmo, 1956). Furthermore, these bodies are very variable in composition. And: and this is the most important feature of these rocks; the potash feldspar (invariably microcline) is there always interstitial and of distinctly later origin than other constituents of the rock (Eskola, 1954 and 1956; Marmo, 1956; Smulikowski, 1958; etc.). This results also in the fact, that the patches of true granite composition, within the synkinematic batholiths, are always limited in size and mainly restricted to the tectonically disturbed or modified portions of the body (Marmo, in several connections).

In his reply, Oftedahl cited the paper of Bott (1957) saying (Oftedahl, 1959, p. 139): "— — — investigations by Bott (1957) and others indicate that *homogeneous granite* bodies ordinarily may have dimensions of 20 km or more in diameter and a thickness of about 8 km". (Italics of the present writer). This reference of the paper of Bott is, however, somewhat inexact, because the granite body investigated by Bott, according to his own rock description (Bott, 1957, p. 46), is not any *homogeneous* granite: "— — — The acid igneous rocks often referred to comprehensively as granite are coarse-grained, crystalline rocks — — —. Subdivision into true granite, adamellite and granodiorite is based on the feldspars. In this paper, tonalites are normally included with the granites." And: "Within a single mass there is often considerable variation of acid rock type . . ." Furthermore, at many places, this rock is gneissose. Consequently, referring to this batholith, in the sense of the discussion of Oftedahl, is incorrect. In addition, according to Bott, even if originally of magmatic origin, the emplacement of this batholith has taken place due to isostatic-type phenomena depending on the "granite" mass deficiency. In the discussion following the paper of Bott, A. F. Hallimond remarked that (discussion after the paper of Bott, op. cit., p. 63): "It would seem that the gravitational results cited might be summarized by saying that the present gravitational profiles did not give any additional contribution such as could be attributed to a structure in the underlaying layer." K. C. Dunham made, in the same connection, a very important and well established question (op. cit., p. 64) whether "a sediment-filled basin would give a similar curve". If batholiths of such kind are metamorphic and partly palingenetically remolten sediment masses, subsequently isostatically displaced (they may even contain magmatic materials, not, however, of granite composition, the potash feldspar of these rocks being invariably definitely younger than other constituents, and obviously emplaced into a *solid rock)* such masses would undoubtedly cause similar gravitational anomalies as do the rocks investigated by Bott. This possibility appears also in the criticism by I. J. Watson (op. cit., p. 65): "The fact that it (anomaly) is usually negative is attributable to the comparatively low density of granitic materials, and has no further significance." And: "Dr. Bott favours an interpretation in terms of post-tectonic granite intrusions, but there seems to be little point in introducing such a conception when a more tenable explanation is available." The last-cited sentence is such that it may well be adopted for many other geological interpretations, as well, including those proposed by Oftedahl for many ore deposits. Consequently, notwithstanding many supporters of the views of Bott, to some extent including also myself, there still seems to be, in the phrases cited, sufficient evidence to prove that taking (by Oftedahl) the work of Bott as prove for the existence of large reservoirs of granite magma is unjustified, and particularly so, because the "granite" studied by Bott, actually was not any homogeneous granite at all.

Thus the comparison between the amount of abscesses of human skin and the abundance of magma reservoirs, presented by Barth, seems still to be much better established.

Albilization

The second point in the reply of Oftedahl, which I would like to discuss somewhat more thoroughly, is that concerning the "spilitization". In my critical remarks (Marmo, 1958) I pointed out, that the porphyries adjacent to the ore bodies often are not of granite composition (in the actual fact, they are seldom granitic). To this Oftedahl remarks that (op. cit., p. 141) "the soda dominance is often so pronounced that the conclusion is inescapable that this is not a primary magmatic composition", and that "this soda dominance must be linked up with the "spilitization" ", and he assumes "that this process simply is the interaction between the Na-rich sea water and hot, acidic glass particles". I would first remark that there must be enormous amounts of very salty water to be able to convert some acid porphyry of granite composition (with 3 to 5 % K_2O) into some acid porphyry containing but 0.3 to 0.1 % K_2O. Still more difficult it is to understand that soda introduced in such a way would be as evenly and thoroughly distributed in the rock as it is in the acid porphyries accompanying some ore bodies. Thus a homogeneous distribution of equigranular plagioclase in the acid porphyries, including the innermost parts of the flows, if caused by spilitization, is really surprising, because one would expect that if extruded under water, the flows would obtain solid crust in few days time; and even before that, any other interaction between the Na-rich sea water and hot lava but a very superficial one, is hardly to be expected. Eskola, Vuoristo and Rankama (1937) have carried out the spilite reaction in the laboratory, but thereby it was necessary to use a temperature of 310—330° C and a duration of 168 hours to obtain albite from a mixture of anorthite and olivine. Similar conditions as effected by a lava extrusion into the water are out of question; and furthermore, the "spilitization" of potash feldspar would be not the same. To my opinion, here is a rather artificial explanation with a very weak, but still theoretically somehow established back-ground. Furthermore, if in these porphyries potash feldspar is present at all, then it often occurs filling the interstices or forming thinny veinlets, only to minor extent being definitely contemporaneous with the plagioclase (as it does in actual granite porphyries). In addition, in most cases examined by the present writer, the plagioclase of these porphyries has not been albite but oligoclase, which makes the application of the spilitization theory still more difficult, if a "spilitization" of potash feldspar is concerned.

The albitization of "granitoids" has been proposed by many other authors, as well, most recently, perhaps, by Smulikowski (1958) who studied the "granitic rocks" of the Sudetic Mountains. There the reason for the supposition of albitization is entirely opposed to that why Oftedahl would like to adopt the spilitization theory. The rocks described by Smulikowski are, in his opinion, of sedimentary origin. Sediments, on the other hand, are usually much richer in potassium than the granodiorites, adamellites, and tonalites, usually mainly composing the "granite" batholiths. Thus, there the granitization is not possible, because this means addition of potassium. The present writer has suggested (Marmo, 1956, 1956a, 1958a), that such circumstances may be due to expulsion of potassium from the regionally metamorphozed sediments (the possibility of which phenomena is theoretically well established, and also often observed in the field). This would then re-appear in the localities of lower free energy (tensional faults and folds, tensional fractures, etc.), in which, in the actual fact, the true granitic portions of a granodiorite batholith usually occur. There it may cause a local granitization, or formation of aplites. By the present author this phenomenon has been termed as granodioritization. The authors favouring the "albitic feldspathization", including Smulikowski, postulate, that there must have been albitization preceeding the granitization (because the potash feldspar in these rocks in invariably distinctly younger than the oligoclase, and because microcline is often replacing plagioclase, the opposite replacement having in these rocks, never been observed). None of these explanations, however, does give any support to the view that even acid porphyries should have been primarily of real granite composition, but then converted into almost potassiumless rocks of quartz-diorite composition. On the other hand, I cannot see there any actual reason, why some kind of hypothetical spilitization or albitization of these porphyries would be thought, because the quartz-diorite composition of these porphyries is in good agreement with certain recent acid lavas, as well. Why these ancient lavas would not be allowed to have had a similar composition? I fail to see there any demand to make the interpretations more complicated than it is necessary.

Discussion

There are two ways to interpret certain phenomena occurring in the nature: either we adopt some general theory and then attempt to make all the observations made in the field to fit into this theory, disregarding other available interpretations which are in variance with that adopted; or each phenomenon observed is attempted to be interpreted in easiest and most plausible way, disregarding the pre-existing theories of general nature, into which the phenomena observed do not fit. I personally prefer the latter alternative. May be I am wrong but still I feel that this is the more correct way of thinking if the granite geology is concerned. The decision between these two alternatives is not only the formal one; in the actual fact, this a decision is of a very fundamental character; it includes the settlement whether the phenomena in the nature follow always similar single ways, or if similar results may be obtained in different ways, as well. In the chemical industry, the same compounds may be produced in very different ways. In the nature, the sulphur bacteria produce sulphur either by reducing sulphates or oxydizing hydrogene sulphides. But a similar sulphur is produced by the volcanic exhalations, as well. Therefore, even the laboratory experiments do not necessarily give us the true natural conditions of the formation of, say, fayalite, and still the end products both in some ultrabasic rocks and in the laboratory experiments are *almost* identical. For these reasons, concerning the granite petrology, the geologist cannot be *either* a magmatist or a metasomatist. He has to consider the both possibilities in each separate case examined by him, and rule out one of these two providing he has sufficient amount of evidence to approve that.

Concerning that part of the theory of Oftedahl which deals with the genetical relationship of granitic exhalations and ores, I fail to see that this a relationship would be sufficiently established, and particularly so because this an establishment seems to depend upon the adoptation of such interpretations which appear as being much more artificial than many other ones available at hand, used for instance by Gray (1958) for the ores of Rhodesian copper belt. But still, the issue of the article of Oftedahl, in my opinion, was very welcome. This is already proved by the fact that it called forth such an amount of discussion as it already did.

References

BOTT, M. H. P., 1957: A geophysical study of the granite problem. Quart. Journ. Geol. Soc., *112*, p. 45—62.

ESKOLA, PENTTI, 1954: Om indelningen av Finlands granitiska bergarter. Geologi (Helsinki), *6*, p. 36—37.

— 1956: Postmagmatic potash metasomatism of granite. Bull. Comm. géol. Finlande, *172*, p. 85—100.

ESKOLA, PENTTI; VUORISTO, URHO, and RANKAMA, KALERVO, 1937 (1935): An experimental illustration of the spilite reaction. — Bull. Comm. géol. Finlande *119*, p. 61—68.

GRAY, ANTON, 1958: The future of mineral exploration. Bull. Inst. Mining Metall., *68*, part 2, p. 21—56.

MARMO, VLADI, 1956: On the emplacement of granites. Amer. Jour. Sci., *254*, p. 479—492.

— 1956 a: On the porphyroblastic granites of Central Sierra Leone. Acta geographica (Helsinki), *15*, n:o 4, p. 1—26.

— 1958: On the theory of exhalative-sedimentary ores. GFF *80*, p. 277—282.

— 1958 a: The problem of latekinematic granites. Schweiz. Miner. Petr. Mitt., *38*, p. 19—42.

— 1958 b: Granite und Erzbildung. Freiberger Forschungsh. C 57.

OFTEDAHL, CHR., 1958: A theory of exhalative-sedimentary ores. GFF *80*, p. 1—19.

— 1959: On exhalative-sedimentary ores. Replies and discussion. GFF *81*, p. 139—44.

SMULIKOWSKI, KAZIMIERZ, 1958: Problem of genetic classification of granitoids. Studia Geol. Polonica, *1*, p. 59—115.

Notis

Morfologiska förändringar på Ivö i samband med »katastrofregnet» den 31 juli 1959

Av

P. O. Persson

Paleontologiska Institutionen, Lund

På eftermiddagen den 31 juli 1959 föll över nordöstra hörnet av Skåne och angränsande delar av Blekinge ett våldsamt regn, som inom en stor del av området fick rent katastrofala följder. Grödan förstördes, byggnader skadades, och på vissa ställen, särskilt på Ivö, där 200 mm regn föll under loppet av 2 timmar, förorsakade vattenmassorna betydande morfologiska förändringar i landskapet. Sålunda bildades på öns västra sida, omkr. 900 m SV norra udden, en mer än 200 m lång, 10—20 m bred och upp till 7 m djup ravin med branta väggar (fig. 1). Ravinen sträcker sig från landsvägen Ivö by—Kaolinbrottet (denna väg blev f. ö. delvis förstörd) och ner till sjöstranden. Den mark, som vattenmassorna genomskurit, består dels av glacifluvial sand och dels av en ganska blockrik morän. Utanför ravinens mynning vid stranden har en deltabildning ägt rum, vilken resulterat i att en ny halvö uppstått (fig. 2). Denna sträcker sig omkr. 40 m ut från den ursprungliga strandlinjen och är ca. 70 m bred. Halvön synes huvudsakligen bestå av grus och sand, men särskilt i dess proximala del

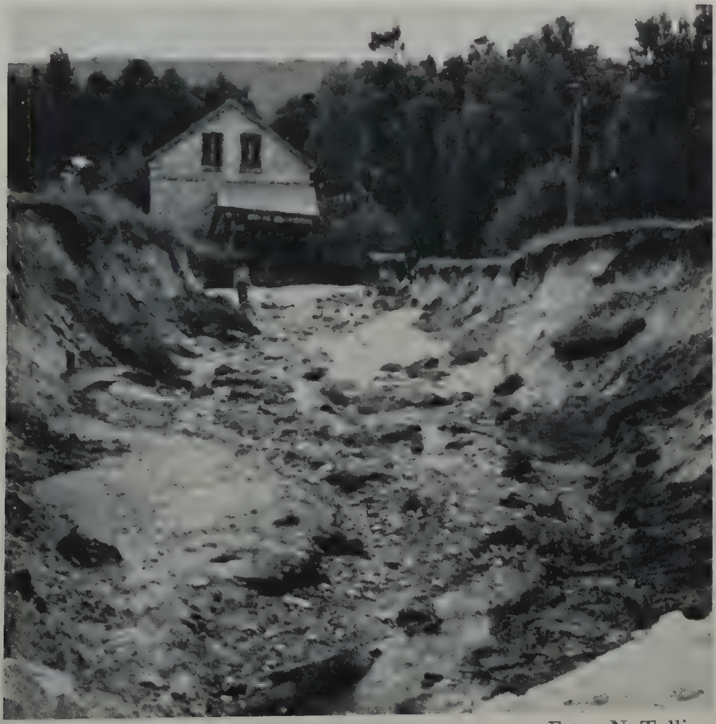


Foto: N. Tulling

Fig. 1. En del av ravinen. Huset till höger är delvis underminerat.

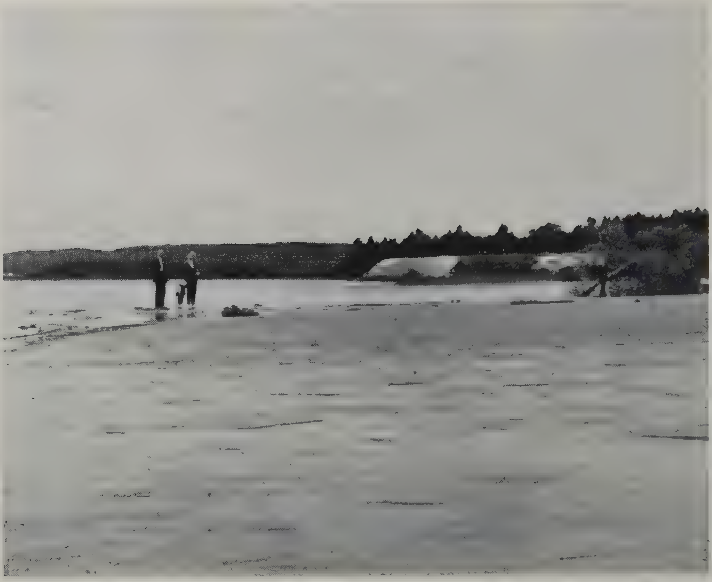


Foto: N. Tulling

Fig. 2. Den nya halvön utanför ravinens mynning.

finnas också ganska stora stenblock samt omkullvräkta träd, som rivits med av vattenmassorna.

På öns östra sida, omkr. 1 km SSO norra udden, har utsköljt material byggt upp ett liknande delta. Den halvö, som sålunda bildats, sträcker sig omkr. 50 m ut från den ursprungliga strandlinjen och är ca. 60 m bred. Någon egentlig ravin har ej bildats här, utan materialet till den nya halvön, vilket bl. a. innehåller kubikmeterstora block av såväl urberg som en mycket hård, grå skalgruskalksten, har sköljts ned från den branta östsidan av Ivö Klack.

Något hundratal meter längre söderut inträffade i samband med regnkatastrofen ett mäktigt jordskred, i det att en omkr. 50 m lång och 40 m bred landmassa invid stranden försköts ca. 10 m utåt sjön. Glidytan tycks ha utgjorts av kalkmorän. På landremsan ifråga växa bl. a. flera stora bokar.

I en fruktodling tillhörande hemmanet Ivö 20: 8, omkr. 1 300 m S norra udden och 100 m från västra stranden, bröt plötsligt ett mäktigt källsprång fram ur marken, som här består av grov, delvis sekundärt cementerad kalkmorän. Vattnet strömmade upp ur ett i det närmaste vertikalt hål med omkr. 0,5 m diameter och bildade en strid bäck ned till stranden. Ännu tre veckor efter regnkatastrofen gav den nya källan mer än 1 000 minutliter vatten, trots att det ej regnat nämnvärt i trakten under dessa tre veckor. Att märka är, att ingen tillstymmelse till bäck eller källsprång funnits på platsen tidigare, men det är naturligtvis tänkbart, att ett utflöde djupt under Ivösjöns yta funnits, och att detta helt eller delvis täppts till genom någon sättning i marken. Troligen finnas vittutgrenade system av temporärt vattenfyllda gångar och håligheter i skalgruskalken och kalkmoränen runt Ivö Klack, och vid nämnda tillfälle har vattnets tryck i dessa blivit så starkt, att vattenmassorna måste bryta sig en helt ny väg.

Verkningarna av ett häftigt regn bli ju i Sverige lyckligtvis sällan så våldsamma som i det aktuella fallet. Att de morfologiska förändringarna på Ivö blivit så stora, beror säkerligen på de säregna geologiska förhållanden, som äro rådande därstädes.

(Manuskriptet inkommet till redaktionen 29 sept. 1959.)

Recensioner

Per H. Lundegårdh: Stenar i färg. Almqvist & Wiksell, Stockholm 1960. 127 textsidor, 64 färgplanscher. Pris i klotband 14: 75.

Till personalen vid Sveriges geologiska undersökning har från allmänheten i många år riktats förfrågningar efter en elementär lärobok på svenska om mineral och bergarter, frågor, som hittills tyvärr ha måst besvaras nekande, då tidigare arbeten av A. Sjögren och L. J. Igelström är starkt föråldrade och dessutom numera knappast står att uppbringa. Föreliggande arbete av statsgeologen och docenten P. H. Lundegårdh fyller sålunda ett länge känt behov.

Arbetet, som är i liten och händig oktav, inledes med en svit av 64 sidor färgplanscher av de vanligaste mineralen och bergarterna, arrangerade i grupper enligt gängse indelningsgrunder. Det avbildade materialet är oftast av svenskt ursprung. I de fall att bättre eller mera karakteristiska stuffer finns i våra grannländer, har förf. dock i första hand låtit avbilda sådana. Färgtrycken är på det hela taget tillfredsställande och i många fall mycket bra. Vissa färglösa eller vita stuffer återges dock i många fall med en tidigare okänd kulör, sannolikt beroende på brytningsfenomen och ljusreflexer vid fotograferingen.

Den beskrivande texten börjar med en klar och lättfattlig redogörelse för kristallsystemen, hårdhetsskalan, den kemiska sammansättningen av jordskorpan samt jordklotets uppbyggnad och efterföljes av en redogörelse för de geologiska processer, som leder till bildning av mineral och bergarter. Flera textbilder i svartvitt finns här. Nästa avsnitt omfattar bestämningstabeller för mineral, och dessa äro baserade på egenskaperna färg, hårdhet, glans, spec. vikt och utbildningsformer. Till detta är fogat en förteckning över svenska huvudfyndorter av malmmineral och en uppräkning av de bergartsbildande mineralen. Även ett antal bergartsbestämningstabeller har konstruerats av förf.

Därpå följer texten till de ovannämnda 64 sidorna färgplanscher, och i denna är tonvikten lagd på svenska förhållanden. Varje mineral behandlas på mellan 10 och 40 rader, vilket får anses vara tillräckligt med hänsyn till bokens karaktär av fickuppslagsverk. När förf. behandlar bergarterna blir texten fylligare än för mineralen och kompletteras ofta med svart-vit-bilder i texten samt redogörelser för skilda namngivna bergartsvarianters särdrag och förekomst m. m., exempelvis artiklarna *Granit, Gabbro* och *Gnejs.* I den sistnämnda av dessa kommer förf. bl. a. in på anläggningar av bergrum.

Arbetet avslutas med ett kapitel om meteoriter, vilket bl. a. inrymmer en kort redogörelse för det intressanta Hesslefallet i Uppland år 1869. Sist följer ett avsnitt med termförklaringar samt ett fylligt sakregister.

Författaren har givit sig i kast med en uppgift, som alla svenska geologer velat se löst men ingen vågat att riktigt på allvar ta itu med. Omdömet blir att han med heder skilt sig från uppdraget att skriva sin del av samlingscykeln om naturen i färg. Naturligtvis finns det alltid något, som varje anmälare skulle vilja ha tillagt till eller borttaget från ett arbete av just denna karaktär. Med hänsyn till den oerhörda mängden av fakta och det ringa formatet på boken är detta en ofrånkomlig sak, som givetvis ej förringar dess värde. Boken kan verkligen med varm hand rekommenderas till en mineralogiskt och geologiskt intresserad allmänhet. Den lämpar sig också som grundkursbok vid högskolor och för bredvidläsning i gymnasiet.

Erik Åhman

D. S. Korzhinski: Physicochemical basis of the analysis of the paragenesis of minerals. Consultants Bureau, Inc., New York—Chapman and Hall, Ltd., London 1959. 142 sidor och 86 fig. (Översättning från den ryska upplagan utgiven i Moskva 1957.)

I den strida ström av sovjetiska naturvetenskapliga skrifter, som i spåren av uppseendeväckande astronautiska triumfer börjat översvämma Occidenten, märks en hel del geologiskt gods. De mer elementära läroböckerna av öststatsmodell har väl trots sina förtjänster i allmänhet föga nytt att erbjuda — mer än det sympatiskt låga priset! Vida viktigare är de alster, som i monografiform tar upp mer avgränsade problem till ingående behandling. En god representant för den senare kategorin är ovannämnda bok, vars ämnesval för övrigt har en stark nordisk förankring med tanke på Goldschmidts och Eskolas pionjärinsatser. Den korrekte förf. har också inledningsvis framfört sina reverenser i vederbörlig ordning.

Först behandlas de termodynamiska lagar, som bildar grundvalen till parageneslärdan. Förf. ägnar sig här främst åt sitt speciella skötebarn, nämligen jämviktstillstånd och termodynamiska parametrar i öppna system, med den petrologiska baktanken att skapa ett teoretiskt underlag för framför allt de metasomatiska processerna. Han inför bl. a. begreppet »lättrörliga» kontra inerta komponenter och utgående från det antagandet, att även system, som undergår irreversibla förändringar, under vissa villkor kan anses befinna sig i jämvikt (»mosaikjämvikt»), tillämpar han fasregeln i något modifierad form på dessa system. Dessa teorier som förutsätter god kännedom om ett så exklusivt ämne som irreversibel termodynamik, förefaller för den oinvigde att vara framlagda på ett mycket vederhäftigt sätt. Kritiska röster har dock tydligen gjort sig hörda, t. o. m. i det egna hemlandet, varom flera polemiska inslag av delvis från natur vittnar.

Den som är road av geometriska konstruktioner kan sedan få sitt lystmäte tillfredsställt, när förf. redovisar olika metoder att grafiskt åskådliggöra den kemiska eller mineralogiska sammansättningen. Här är det inte bara frågan om de klassiska liksidiga triangeldiagrammen utan en för geologiska sammanhang ovanligt uttömmande inventering av de möjligheter, som modern projektionsgeometri förfogar över.

Även bokens senare del är utpräglat teoretisk, men här läggs tyngdpunkten på själva mineralparagenesen. Efter att ha givit en del nödvändiga definitioner och bl. a. utvecklat sina synpunkter på innebörden av mineralfaciesbegreppet behandlar förf. sambandet mellan den mineralogiska sammansättningen och de olika faktorer, som kan påverka densamma. För att åskådliggöra systemens tillståndsändringar kommer huvudsakligen kemiska potentialdiagram och ekvipotentialkurvor till användning. Förf. illustrerar sina tankegångar med geologiska exempel, huvudsakligen hämtade från sitt eget arbetsfält, det östsibiriska urberget. Som ett smakprov kan nämnas hans undersökning av ett gnejsområde med den stabila mineralassociationen: kvarts-ortoklas-plagioklas-biotit-hornblände-klinopyroxen-hypersten. Efter nödvändiga förenklingar räknar han ut jämviktsekvationer för de monovarianta reaktioner, som kommer i fråga. Därefter konstruerar han ett paragenesdiagram med de kemiska potentialerna för Na_2O och K_2O som variabler (= de lättrörliga komponenterna; μH_2O liksom P och T är konstanta), där de monovarianta jämviktsreaktionerna representeras av räta linjer, vars vinkelkoefficienter bestäms av det för reaktionen karakteristiska molförhållandet K_2O:Na_2O. Dessa linjer avskiljer i sin tur olika bivarianta fält, som vart och ett utmärker en paragenestyp. Inom ett och samma fält kan alltså sammansättningen varieras utan att paragenestypen ändras. I det sammanhanget betonar förf. plagioklasmineralens stora betydelse som »subfacies-indikatorer».

Det kan tilläggas, att det bl. a. fordras viss kännedom om determinantteorien för att få fullt utbyte av förf.:s originella framställningssätt. Trots de teoretiska utsvävningarna håller sig förf. dock kvar på jorden, när han i slutkapitlet uttryckligen framhåller, att det är betydligt lättare att från ett givet utgångsläge och under givna betingelser härleda stabiliteten av en viss mineralassociation än att gå den motsatta vägen. Denna nedslående sanning förringar dock inte på något sätt det lovvärda initiativ, som tagits av Geochemical Society för att öka den regionala spridningen av detta intressanta arbete.

Bengt Lindqvist

J. A. Jacobs, R. D. Russel, J. Tuzo Wilson: Physics and Geology, — McGraw-Hill Book Company, Inc. New York 1959. 424 p.

Denna bok är en utvidgning av de kurser i geofysik, som de tre författarna givit studerande i geologi och fysik vid universitetet i Toronto. De ha därvid velat ge de förstnämnda en introduktion i jordens fysik och studerande inom andra ämnesområden någon kännedom om geologin och dess relation till geofysiken.

Innehållet i boken täcker väl de ämnen, som ha föreslagits vid en utbildning av geofysiker vid svenska universitet. Bokens 17 kapitel omfattar sålunda följande ämnen: universum och solsystemet, seismologi och jordens sammansättning, jordens form och tyngdkraften, jordens termiska historia, geomagnetism, den övre atmosfärens fysik, geokronologi, isotopgeologi, jordmateriens mekaniska egenskaper, undersökningar av oceanernas bottnar, marina centralryggar, ögirlander och bergskedjor, inaktiva bergskedjor och kontinenter, bildningen av jordens ytformer samt glaciologi.

Varje kapitel kan läsas som en avslutad enhet, och framställningen har gjorts lättförståelig även för dem, som inte ha någon djupare matematisk kunskap. För de teoretiskt intresserade finnas sex bilagor, i vilka den matematiska behandlingen av utvalda problem om fundamentalsatser gives. Innehållet i de olika kapitlen är av något ojämn kvalitet, då det på det begränsade antal sidor, som stått till buds, ibland har varit svårt att överskådligt behandla så stora ämnesområden. I den mån innehållet kunnat kontrolleras, ha inga sak- eller tryckfel påträffats. I sin helhet har boken mycket att bjuda både äldre och yngre geologer, framför allt dock de senare, i det den ger en god men inte för ingående översikt av den geofysiska vetenskapen. Vill man nämna något avsnitt framom de andra, torde det korta kapitlet om jordens termiska historia samt behandlingen av geokronologin framhållas. Särskilt det sistnämnda kapitlet är en utmärkt introduktion i de nu använda metoderna.

Erik Welin

Simpson, G. G., Roe, A., Lewontin, R. C.: Quantitative Zoology. Harcourt, Brace and Co., Inc., New York-Burlington: vii + 440 pp. Printed February, 1960.

The second, largely rewritten, edition of *Quantitative Zoology* has appeared 21 years after the first. During this period of time much has happened in the biometrical world, and most English-speaking zoologists, and a few paleontologists, have at least a nodding acquaintance with statistical methodology. This was, however, not the case in 1939, the year of first appearance of the book, when the biological attitude to the subject was often hostile. The situation now is different thanks largely to its influence. British and American taxonomists are commonly required to undergo some training in biometry, and this fact has prompted the authors to suitably modify the original layout. A result of this is that the book is now more a textbook for class instruction.

The contents of the second edition are much the same as those of the first and the only major addition is a chapter on the analysis of variance. A good deal of the original arrangement of the topics has been reshuffled. It might be asked why some of the recent advances in the biometric application of multivariate statistical analysis have not been taken into account. The textbook under review is, however, introductory and in order to have included multivariate techniques it would have been necessary to make the entire volume mathematically more advanced.

The present reviewer prefers the style of the first volume. It is tiring to have the captions to the figures in the same style as the body of the text and the procedure of the first edition of printing the illustratory examples in a different type would have bettered the second edition. The following tables are provided in an appendix: Areas and ordinates of the standardized normal curve, table of t, table of χ^2, table of F, and significance properties for the correlation coefficient. This procedure is an improvement over the original arrangement with the tables located in the main text. There is also a glos-

sary of symbols (the usual mathematical abbreviation for covariance is cov and not cov.).

In the first chapter a discussion on zoological variables is presented, as well as observations on the meaning of significant figures. The notes on the role of indices are particularly interesting. The second chapter is concerned with aspects of mensuration: it should be brought home to the student that no amount of mathematical manipulation will make up for incorrect measuring techniques, and he would be well advised to read the section carefully before attacking his problems. Frequency distributions and the concept of grouping are reviewed in the next chapter. The application of the arithmetic mean is treated at length. The procedure accepted in the first volume, known as the »assumed mean method», is quite rightly dropped. This chapter also includes the median and the mode, the treatment of these statistics being much the same as in the first edition. Dispersion and variability are treated in about the same way as in the first edition, but the usage of symbols has been modernized. One of the rather irritating sides of the first edition was the almost exaggerated use of footnotes, in which more difficult points and notes on derivations were presented. This made itself particularly felt in the section on dispersion. In the present edition footnotes have been slashed to a minimum, the information formerly included in them now being incorporated in the running text, or entirely omitted. A section on sampling useful to the paleontologist and zoologist follows. This includes a brief note on the capture-recapture method, the mathematical theory of which has attracted much attention of late. The method of quadrat sampling, which originated in Scandinavia, is discussed. It might have been useful to have an account of the improvement introduced by Greig-Smith in 1952 and its more recent mathematical extension by Thompson in 1955. Although this newer theory is based on plants it is also applicable to many groups of animals. Its chief virtue lies in the fact that it permits the use of the analysis of variance.

A chapter is devoted to probability and probability distributions in which the binomial distribution, the Poisson distribution, and the normal distribution are discussed. Parts of the chapter are extensively rewritten and modernized. The paragraphs on skewness and kurtosis are largely unaltered, but the setout is better, and at least one inaccuracy in calculation is corrected. The present reviewer would have preferred a more up-to-date treatment of these two statistics plus their standard errors, in accordance with recent standard texts on applied statistics (e. g. Snedecor, 1956). A valuable betterment is provided by the chapter on confidence intervals, which is in part a rewritten version of the original section entitled »Probability and Reliability». The common univariate standard errors are placed here.

The section on testing the difference between the means of two samples has been brought up to date; the chapter may be claimed to be a veritable Eldorado of useful information. The student is advised to understand the principles underlying the remarks on paired comparisons (pp. 180—182), for this concept is of much use in multivariate connexions. The subject of heterogeneity of variance is now more widely treated, although only for two samples. The reviewer feels it would have been a good idea to have taken up Bartlett's test of homogeneity of variance, considering that it is of such use in the analysis of variance; the calculations are simple, and it is now standard in statistical texts.

The standpoint adopted in the chapter on correlation and regression is illuminating for the paleontologist, and even advanced biometricians may be able to pick up useful information and thoughts there. Particularly the touchy problem of whether correlation or regression is justifiable in a given situation is provided with a timely discussion. The authors arrive at the conclusion that despite statements to the contrary, the zoologist may continue to use classic regression methods, whether or not one of the variables has been deliberately chosen to take prassigned values. The authors advise against the usage of the regressional methods of »major axes» and »reduced major axes». An acount is given of Bartlett's »best-fit» straight line method. The text treating correlation is substantially the same as before. The correlation ratio is not included in the second edition.

The chapter on »Association» of the old edition is now partly taken up in a new chapter entitled »Tests on Frequencies», and partly redistributed elsewhere. Three problems are treated, using the chi-square technique, that apply to discrete variates, namely, the »goodness-of-fit» test of observed frequencies to theoretical, testing the similarity of distribution of two or more populations, and association between two or more attributes. The treatment of graphic methods in taxonomy, although slightly enlarged, is fundamentally little altered from the 1939 version.

The section on growth has been much expanded. It contains much useful information and is doubtlessly the most valuable single contribution of the whole book. It is to be hoped that students of animal growth will take the advice offered concerning plotting of the raw observational data before plunging into an ill-considered mishmash of logs and curve-fitting. The importance of the difference between the allometry of growth and size is discussed.

Chapter 12 is concerned with *analysis of variance.* This section is introduced with a discussion of the taxonomic application of the technique. The analysis of variance has one of its greatest applications in agronomy. Compared with this science, the number of factors of interest to the zoologist and paleontologist are more restricted. The authors suggest that the factors of time, locality, environment, physiology, taxonomic categories, and techniques are the main ones in zoology. The form of the analysis of variance included may be summarized as below: For the fixed model — one factor designs, the analysis of variance in regression (this replacing the correlation ratio of the first edition as a test of rectilinearity of regression), two factor designs, and three factor designs. The three factor design is not provided with a worked example, which would have been helpful to the student, bearing in mind the background of that section of the scientific public to which *Quantitative Zoology* is addressed. The random factor type of model is provided with the same design as above. A section is also given which involves mixed models, in which the factors cannot be classified as all-fixed or all-random; for example, a problem involving sympatric species (fixed) in a series of randomly chosen localities (random). Finally, tested models are treated, which involve, for instance, the common zoologic case where factors are not factorially related. If any criticism is to be made of the section on variance analysis it would be that there are too few worked examples, and none with a direct paleontological flavor. It is to be remembered, that still too few universities provide instruction in biometry and many workers attempting to apply quantitative methods to their problems will be laboring alone and unaided. The section demonstrates adequately the power of the technique in connexion with quantitative problems.

Finally one of the overall improvements is the consideration taken to machine calculation throughout. There can be no doubt that the zoological-paleontological student will receive an excellent insight into the meaning of statistics in biology with the help of the book under review. *Quantitative Zoology* is an absolute necessity for all students of neo- and paleozoology.

R. A. Reyment

R. B. Behrmann: Die geotektonische Entwicklung des Apennin-Systems. (Geotektonische Forschungen häfte 12.) E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart 1958. 99 s., 15 fig., 2 pl.

I den trevliga publikationsserien »Geotektonische Forschungen», som utges av H. Stille och Fr. Lotze, har nu en av Behrmann skriven översikt om Apenninsystemet utkommit. Stilles lärjungar A. Pilger, H. W. Quitzow, G. Richter, J. Schneider, R. Teichmüller och R. B. Behrmann har under trettiotalet utfört fleråriga geologiska undersökningar i Apennin och grannområden, vilka Behrmann nu sammanfattningsvis bearbe-

tat. I boken är även den nyare italienska litteraturen inarbetad. Behrmann, som har mångårig erfarenhet från praktiskt geologiska arbeten för ett amerikanskt oljebolag i Italien, behärskar stoffet suveränt och tecknar i korta lättfattliga meningar Apenninsystemets tektoniska utveckling. Uppställningen i de olika kapitlen är mycket klar och översiktlig och även en icke specialist på italiensk geologi får tillfredsställande insikter i nuvarande föreställningar om områdets geologiska byggnad och historia och dessutom, vilket måste anses betydelsefullt, på vilka fältförhållanden dessa är grundade. Figurerna i boken, vilka uteslutande består av tuschtecknade profiler, kartskisser och principskisser, kompletterar texten.

Området intar, såsom länge känt, en tektonisk nyckelposition mellan Västalperna i norr, Dinariderna i öster och Atlas i Nordafrika, genom att det veckade området bildar en S-formig båge. Västalperna med sin nord- respektive västvergenz slutar i Medelhavet sydost om Corsika, medan Apenninerna, Dinariderna och Atlas har ostlig respektive sydlig vergens. Både Västalperna och Apenninerna härstammar i Norditalien ur samma geosynklinal, vilket kan bevisas genom sedimentens facies. Väster om Genua är dock vecken överstjälpta och överskjutna mot väster, medan öster om Genua rörelseriktningen i de liguriska skållorna lika entydigt är riktad mot öster. Längre i söder ingår andra element i den Apenninska fjällkedjan, och förhållandena blir mera svårtydda.

Boken kan rekommenderas att medtagas som komplement till en geologisk karta, om en geolog vid en resa till Italien till äventyrs skulle ha för avsikt att också lära känna något om landets geologi.

Gunnar Kautsky

Mötet den 3 mars 1960

Närvarande 37 personer.

Ordföranden, hr Asklund, öppnade sammanträdet och meddelade följande:

Den 5 februari avled fysikern och sedermera geofysikern professor Gustaf Adolf Ising i en ålder av 77 år. Ising var född i Finja, Kristianstads län, den 19 februari 1883. Han tog fil. kand.-examen i Uppsala 1903 och fil. lic.-examen vid Stockholms Högskola 1910. År 1919 disputerade han på en avhandling »Undersökningar över galvanometrar», samt blev därvid docent vid Högskolan och var åren 1920—28 t. f. professor i fysik vid Högskolan. År 1934 tillades han professors namn. Åren 1945—1953 var han speciallärare i geofysikalisk malmletning vid Tekniska Högskolan. Det är en rik forskargärning som Ising presterat, vilken på flera områden når in på geologiens landamären. Under Stockholms Högskole-tiden konstruerade han bland annat en portabel gravimeter, som för fältbruk fick stor betydelse för de tidigare gravimetriska undersökningarna i vårt land, bl. a. i Skåne. Under 1930-talet inredde Ising ett geofysikaliskt laboratorium i sin villa i Djursholm, där en rad betydelsefulla arbeten utfördes. Här fulländades vad som i dag betecknas som Isinggravimetern. Här upptogos undersökningarna av den varviga lerans magnetiska egenskaper i syfte att bestämma det jordmagnetiska fältets riktning vid tiden för lerans avsättning. Med utgångspunkt från De Geers lervarvskronologi gavs därvid en metod för studiet av jordmagnetismens sekulära variationer. I övrigt gåvo undersökningarna uppslag för en objektiv bestämning av varvsgränserna m. m. Undersökningarna få betraktas som banbrytande för en fortsatt forskning. — Efter gravimetern utvecklade Ising en ny princip för magnetometern med användande av torsionsband och han angav därmed den nya utformningen av instrumentet.

Hans studier över den Brownska rörelsen syftade till konstruktion av högkänsliga galvanometrar, och hans tidigare forskning över elektriskt laddade partiklars acceleration hade principiell betydelse för utformandet av cyklotronen. Särskilt för de sistnämnda pionjärinsatserna tilldelades Ising år 1954 Vetenskapsakademiens Svante Arrhenius-medalj.

Geologiska Föreningen tillhörde han sedan 1937. Han hade genom åren vissa förbindelser med geologkretsar och besökte Geologiska Föreningen, när något ämne avhandlades, som låg hans egen forskning nära. Vi minnas med vänskap och saknad hans för-

Sammandrag av Geologiska Föreningens räkenskaper 1959

Debet

BALANS TILL ÅR 1959

Reservfondens konto	21 588: 43	
Fond för redigering av Rev. Annuelle	3 439: 96	25 028: 39

INKOMSTER UNDER ÅR 1959

Reservfondens konto, räntemedel	713: 79	
Sparkasseräkningen, räntemedel	483: 09	
Naturvet. Forskningsrådet. Anslag 1959	21 000: —	
Jernkontoret, bidrag 1959	2 000: —	
Ledamotsavgifter, årliga	8 981: 27	
» , ständiga	3 000: —	
Försäljning av Geol. Fören. Förhandl.	6 329: 68	
Annonsintäkter	2 275: —	
Sv. Fören. för lerforskn. Tryckningsbidrag	1 665: —	
Diverse	—: 20	46 448: 03
	Summa kronor	71 476: 42

Kredit

UTGIFTER UNDER ÅR 1959		
A. Geol. Fören. Förhandlingar		
Tryckning av årgång 1959	33 551: 62	
Illustrationer	2 857: 45	
Referatarvoden	378: 20	
Distribution, försäljning. Omkostnader	981: 94	
Expeditionskostnader	1 120: 30	
Arvoden för red. distrib. bokföring	2 750: —	41 639: 51
B. Föreningskostnader		
Föreningens sammanträden och repr.	1 020: 72	
VII:e Nord. Geologmötet 1958	115: —	
Bokförrådet	439: 60	
Diverse	233: 20	1 808: 52
BALANS TILL ÅR 1960		
Reservfondens konto	24 588: 43	
Fond för redigering av Revue Annuelle	3 439: 96	28 028: 39
	Summa kronor	71 476: 42

synta stilla väsen och skarpa intelligens. — Frid över Gustaf Isings minne.

Styrelsen har till ledamot av Föreningen invalt fil. stud. Bo Meierhöffer, Stockholm, föreslagen av hrr Lundegårdh och Åhman.

Därefter upplästes revisionsberättelsen över 1959 års förvaltning och tillstyrktes revisorernas förslag om ansvarsfrihet.

Ordet överlämnades sedan till hr P. H. Lundegårdh, som höll ett med talrika färgbilder och kartor illustrerat föredrag med titeln: Sedimentbergarterna i Härnöseriens botten och deras omvandling. I anledning av föredraget yttrade sig hrr Asklund, Gavelin, G. Kautsky, N. H. Magnusson och föredragshållaren.

Mötet den 7 april 1960

Närvarande 56 personer.

Ordföranden, hr Asklund, öppnade sammanträdet och anförde följande:

Sedan Föreningens sista sammanträde har budet ingått att dess ledamot bergsingenjören Halvar Löwenhielm avlidit den 20 mars.

Carl Gustaf Halvar Löwenhielm var född i Askers socken, Örebro län, den 4 maj 1887. Han utexaminerades från Kungl. Tekniska Högskolans bergsavdelning år 1911. Efter konditioner som gruvmätare i Malmberget samt som biträdande gruvingenjör vid Filipstads Bergslags gemensamma förvaltning blev han gruvchef vid Långgruve Bolag med Långgruvan och Lövsvedsgruvan åren 1916—1927. År 1927 blev han förvaltare och chef för SKF Hofors Bruks gruvavdelning, omfattande Nyängsgruvan och Storstrecksgruvan under arbete. Denna befattning lämnade han med pension år 1952 samt blev år 1953 verkställande direktör för AB Smålands Taberg. — Sin största insats gjorde Löwenhielm som chef och ingenjör vid SKF-gruvorna, vilka under hans tid utvidgades med flera nya malmfält. Under hans tid inträffade i samarbete med Bolidens Gruvaktiebolag den betydelsefulla upptäckten av den nu igång varande gruvan Vingesbacke i Torsåkers s:n, som medfört en högst väsentlig förstoring av SKF:s malmbas.

Löwenhielm gjorde redan tidigt flera viktiga maskinkonstruktioner för anrikning, bland andra en magnetisk malmseparator, Löwenhielmseparatorn, som fått spridning långt över Sveriges gränser. Han stod hela livet geologkretsen nära. Ett uttryck härfö var hans insats att tillvaratага ett viktigt mineralfynd i Storstrecksgruvan, där en kristallgrotta med osedvanligt stora och ytrika kalkspatkristaller anträffades, och vilket stora fynd år 1937 överlämnades till Riksmuseets mineralogiska avdelning. I samband därmed erhöll Löwenhielm Kungl. Svenska Vetenskapsakademiens Linnémedalj i silver.

Halvar Löwenhielm blev medlem i Geologiska Föreningen år 1912. Han var en dugande man, vänsäll och glad och efterlämnar i vänkretsen, som det var även mig förunnat tillhöra, minnet av en sann riddersman.

Jag lyser frid över den bortgångnes minne.

Till ledamot av Föreningen har styrelsen invalt tekniker Jan-Olof Jonasson vid S. G. U., Stockholm, föreslagen av hr B. Dahlman och fröken Anne Reintamm.

Professor Erik Norin, Uppsala, har uppvaktats med telegram på sin 65-årsdag den 15 mars. Tackskrivelse har ingått.

Statsgeologen Fritz Brotzen har utsetts att representera Geologiska Föreningen vid Institut de Géologie 40-årsjubileum i Warschava den 10—16 maj 1960.

I anledning av en vädjan från Massachusetts Institute of Technology om ett bidrag till »The Waldemar Lindgren Memorial Fund», som grundats på 100-årsdagen av vår frejdade landsmans och korr. ledamots födelse upptogs en kollekt, som inbringade kr 66:10.

Ordet överlämnades därefter till dr phil. Tore Gjelsvik, Oslo, som höll ett med kartor och talrika ljusbilder illustrerat föredrag med titeln: Kisproblemet i den kaledonske fjellkjede. I anledning av föredraget yttrade sig hrr N. O. Bergquist, J. Eklund, E. Grip, G. Kautsky och föredragshållaren.

Hr Grip tackade för den utmärkta översikten över de norska kismalmerna i fjällkedjan och konstaterade hur lika kismalmer är vilken ålder de än har. Sålunda kunde man peka på väsentliga likheter mellan de norska kaledoniska malmerna och Skelleftefältets kismalmer. Ett påfallande drag hos båda är zink-kopparfördelningen i malmerna. Som föredragshållaren visat, finns i Skorvas en tydlig uppdelning i zinkrika och kopparrika partier. De båda metallerna trivs inte ihop och det finner man också i Skelleftefältet. Om man ritar kurvkartor över metallhalterna ser man tydligt, hur områden med högre kopparhalter visar låga zinkhalter och tvärtom. Ofta kan man visa, hur uppdelningen i olika fraktioner kommit till i samband med tektoniska rörelser och över huvud taget har sådana spelat en mycket stor roll under malmbildningsprocesserna. I Kristineberg t. ex. kan de tre väsentliga malmtyperna direkt sättas i förbindelse med tre tektoniska faser med olika tryckriktning. Kanske något liknande förekommer i de norska kismalmerna!

Geolognytt

Till e. o. statsgeolog vid Sveriges geologiska undersökning har förordnats e. statsgeologen fil. lic. Hans Sarap.

Till den ledigförklarade professuren i geologi, särskilt petrografi och mineralogi, vid Uppsala universitet har följande sökande anmält sig:

Docenten fil. dr Otto Brotzen, Stockholm
Fil. dr Nils Edelman, Boliden
Docenten, Dr phil. fil. lic. Hans J. Koark, Uppsala
Docenten fil. dr Pontus Ljunggren, Lund
Statsgeologen, docenten fil. dr Per H. Lundegårdh, Danderyd
Professorn Dr rer. nat. Otto Mellis, Stockholm

Statens naturvetenskapliga forskningsråd har tilldelats prof. Erik Norin och laborator Sten Florin ett anslag för sedimentologiska och granulometriska undersökningar.

Fil. dr Vladi Marmo har förordnats till chef för Finlands geologiska forskningsanstalt.

Docenten och Intendenten Erik Jarvik har utnämnts till professor vid Naturhistoriska Riksmuseet.

Prof. E. Norin, Uppsala, har föreslagit prof. Hans Ramberg, Minas Gerais, att kallas till den vid Uppsala universitet ledigförklarade professuren i geologi, särskilt petrografi och mineralogi. Till sakkunniga har utsetts professorerna S. Gavelin, S. Hjelmqvist och F. E. Wickman.

Sveriges geologiska undersöknings fältarbeten 1960

Professor G. Lundqvist leder rekognosceringen av jordartskarta över Gävleborgs län.
Extrageologer: R. Bergström, P. Engqvist och S. Holmberg.

Professor B. Asklund utför detaljkarteringar i Tåsjö-området och norra Jämtland betr. den kambriska lagerföljden för karta och beskrivning över fjällkedjeranden. Dessutom påbörjar han översiktskartering inom södra delen av Jämtlands län.
Extrageolog: A. Strömberg
Avslutar förberedelserna för exkursion A24, C19 tillsamman med e. statsgeologen P. Padget och geologen G. Stålhös.

Statsgeolog O. Kulling avslutar berggrundsrevisionen i norra delen av fjällkedjan mellan Torneträsk och Akkajaure.
Extrageologer: N. Marklund och S. Yngström
Avslutar förberedelserna för exkursionerna A25, C20

Statsgeolog F. Brotzen avslutar förberedelserna för exkursion A21, C16 tillsammans med fil. dr B. Lundblad.

Statsgeolog W. Larsson utför berggrundsrevision å kartbladet Falkenberg samt speciella berggrundsgeologiska undersökningar för K. Vattenfallsstyrelsen.
Avslutar förberedelserna för exkursion C27 tillsammans med professor H. von Eckermann.

Statsgeolog P. H. Lundegårdh leder berggrundsrekognosceringen i Gävleborgs län.
Extrageologer: R. Gorbatschev, B. Lindqvist, Th. Lundqvist och N. B. Svensson.
Avslutar förberedelserna för exkursion A28, C23 tillsammans med professor S. Gavelin.

Statsgeolog S. Fromm utför kvartärgeologiska specialundersökningar i norrländska älvdalar.

Laborator S. Werner leder och samordnar samtliga geofysiska arbeten för malmletningen.

Statsgeolog E. Mohrén utför hydrologiska undersökningar i NV Skåne samt deltar i förberedelserna för exkursion A20.

Statsgeolog G. Kautsky leder och samordnar samtliga malmletningsarbeten samt innehar den direkta ledningen för de malmgeologiska arbetena i fjälltrakterna.
Extrageologer: B. Meyerhöffer, R. Randmetz, E. Zackrisson.
Avslutar förberedelserna för exkursion A32, C26 tillsammans med e. statsgeolog R. Frietsch och geolog E. Åhman.

Statsgeolog J. Lundqvist leder jordartskarteringen inom Jämtlands län samt utför specialundersökningar i vissa norrländska älvdalar.
Extrageologer: H. Bredhe, P. Svensson, S. Svensson, A. Wikström.
Avslutar förberedelserna för exkursion C15 tillsammans med statsgeolog E. Fromm och geolog H. Möller.

E. o. statsgeolog B. Dahlman leder specialundersökningar rörande Sveriges alunskiffrar.

E. o. statsgeolog H. Sarap leder de malmgeologiska arbetena i Västerbottens urberg.
Extrageolog: B. Meyerhöffer.

E. statsgeolog R. Frietsch leder de malmgeologiska arbetena i Norrbottens läns urberg.
Extrageolog: F. Back.
Deltar i förberedelse för exkursion A32, C26

E. statsgeolog P. Padget leder de malmgeologiska arbetena i södra Norrbotten.
Extrageolog: M. Johansson.

E. statsgeolog H. Tullström leder undersökningar i Göta älvs dalgång, utför hydrogeologiska undersökningar i NÖ Skåne samt för vissa uppdragsgivare.
Extrageolog: L. Tullström.
Avslutar förberedelserna för exkursion A20 tillsammans med docent C. Caldenius

och statsgeolog E. Mohrén.

Bergsingenjör O. Back leder diamantborrnings- och blottningsarbeten samt transporter i Norrland.

Geolog B. Järnefors leder jordartskarteringen å geologiska kartbladet 10I Stockholm SV.

Extrageologer: Bestämmes senare.

Geolog E. Åhman företar tjänsteresor i samband med utmålsläggning och inmutningsärenden samt utför specialkarteringar i samband med malmletningsarbeten i Norrland.

Deltar i förberedelser för exkursion A32, C26 tillsammans med statsgeologerna G. Kautsky och R. Frietsch.

Geofysiker L. Granar leder de geofysiska arbetena i Västerbottens och Jämtlands län samt i södra Norrbotten.

Extrageofysiker: L. Denslow.

Geolog G. Stålhös utför berggrundsrevision å kartbladet 10I Stockholm NO och leder berggrundsgeologiska undersökningar för kartbladen 10I Stockholm NV samt 10I Stockholm SV.

Extrageolog: O. Kint.

Geofysiker J. Espersen leder de geofysiska arbetena för LKAB.

Geokemist K. Fredriksson utför försök rörande geokemisk prospekteringsmetodik i Västerbotten.

Medhjälpare: I. Lindgren.

Geolog H. Möller leder jordartskartering på geologiska kartbladet 10I Stockholm NV, avslutar revisionen å 10I Stockholm NO samt leder kurs för nya extrageologer inom Stockholmsområdet.

Extrageologer: L. Andersson, K. A. Kornfält, I. Lindqvist och U. Miller samt efter genomgången extrageologkurs B. Båveryd, H. Mårtensson, S. Rydström. I arbetet deltar även exp.vakt R. Svensson.

Utför specialundersökningar i Luledalens nedre del.

Förbereder exkursion C15 tillsammans med statsgeolog J. Lundqvist.

Geolog G. Nilsson utför malmgeologiska undersökningar i Övre Norrland.

Geolog S. Holmberg utför torvundersökningar i Gävleborgs och Jämtlands län.

Geolog A. Reintamm utför specialundersökningar rörande Sveriges alunskiffrar.

Geolog T. Parak utför malmgeologiska undersökningar för LKAB.

Geolog S. Henriksen utför malmgeologiska undersökningar för LKAB.

Assistent C. Larsson utför torvmarksundersökningar för jordartskartan över Gävleborgs län och å kartbladen 10I Stockholm NO resp. NV.

Biträde: K. A. Malmsten.

Assistent A. Theolin utför malmgeografiska arbeten i Övre Norrland.

Ingenjör B. Karlemo utför geofysiska arbeten i Övre Norrland.

Vidare medverkar följande personer i fältarbetet:

Professor S. Hjelmqvist, Lund, kollationerar samman med statsgeolog P. H. Lundegårdh bergartstyper och bergartsgränser i norra delen av Kopparbergs län och nordvästra delen av Gävleborgs län.

Docent H. Koark, Uppsala, slutför strukturundersökningar i Norra Kärr-området.

Nedanstående, ej vid SGU anställda personer, som deltager i avslutandet av förberedelserna för exkursioner i samband med internationella geologkongressen 1960, erhåller därvid resebidrag från SGU:

Docent C. Caldenius, Geol. Inst., Stockholms högskola, för exkursion A20, se Tullström.

Professor H. von Eckermann, Edeby gård, Ripsa, för exkursion C27.

Professor S. Gavelin, Miner. Inst., Stockholms högskola, för exkursion A28, C23 och i samband därmed berggrundsgeologiska undersökningar i Västerviksområdet.

Docent J. E. Hede, Paleont. Inst., Lund, för exkursion A22, C17.

Docent W. Jaanusson, Paleont. Inst., Uppsala, för exkursion A23, C18, se Thorslund.

Docent M. Lindström, Paleont. Inst., Lund, för exkursion A22, C17, se Kulling resp. Regnéll.

Professor N, H. Magnusson, Valhallavägen 46, Stockholm Va, för exkursion A26, C21.

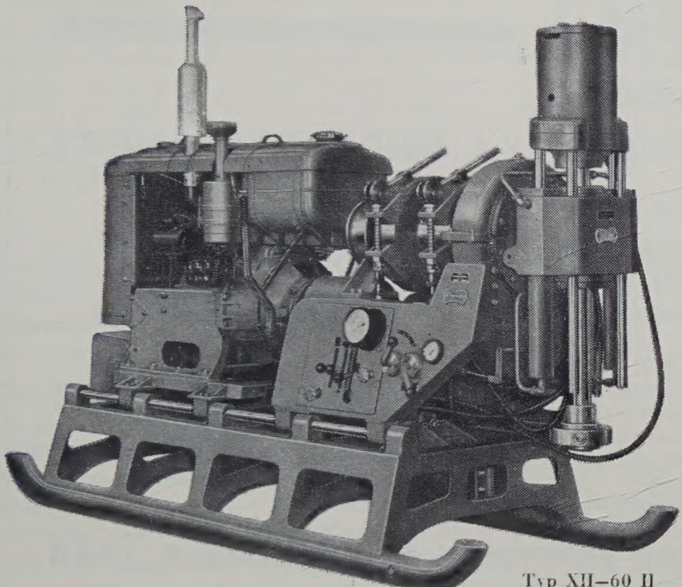
Professor G. Regnéll, Paleont. Inst., Uppsala, för exkursion A22, C17.

Professor P. Thorslund, Paleont. Inst., Uppsala, för exkursion A23, C18.

Dr phil. Tore Gjelsvik, Sandvika, har utnämnts till direktör vid Norsk Polarinstitutt, Observatoriegt. 1, Oslo.

Rättelse

I slutet av medlemsförteckningen, h 1, s. XVI, har genom ombrytningsfel oriktiga rubriker kommit att tryckas. I st. f. Ledamot invald den 4 februari 1960 skall stå Ledamöter invalda den 7 januari, och i st. f. Ledamöter invalda den 4 februari 1960 skall stå Ledamot invald den 4 februari 1960.



Typ XH–60 H

Craelius **KÄRNBORRMASKINER**

PROSBER, bärbar	40 m
X—2 S, luftdriven	125 m
X—4, luftdriven, för spränghålsborrning	100 m
XC—33,5, XC—42, el-, luft- eller kilremsdriven, för spränghålsborrning	125 m
XC—33,5, XC—42, slädmonterad	250 m
XC—60 H, XC—90 H, slädmonterad	300 m
XF—60 H, XF—90 H, slädmonterad	600 m
XH—60 H, XH—90 H, slädmonterad	900 m
XL—90 H	1200 m
XO—150 H	2000 m
AB—2, AB—50	350 m
B—3, B—31	1200—1500 m
B—35, B—36	3000—3500 m
B—41, B—42	3000—4000 m

Vi utför även undersökningsborrningar och brunnsborrningar på kontrakt med egna maskiner och erfaren personal.

SVENSKA DIAMANTBERGBORRNINGS AB

Kungsgatan 44, Stockholm — Postbox 3113, Stockholm 3
Telegram: Adamante — Telex: 1459 — Telefon: 23 33 80

ABEM

utför GEOFYSISKA UNDERSÖKNINGAR

FRÅN LUFTEN
PÅ MARKEN
UNDER VATTEN
I BORRHÅL

för Malmletning
för Oljeletning
för Byggnadsprojektering

tillverkar och försäljer

Magnetometrar
Gravimetrar
Oscillografer
Galvanometrar
Transistor-omvandlare

E. M. Gun, Turam och Kompensator
Apparatur för självpotential- och jordmotståndsmätningar
Seismisk apparatur för reflexions- och refraktionsmätningar

1923 AB ELEKTRISK MALMLETNING 1960

Danderydsgatan 11, Stockholm Ö. Tel.: 23 02 55

ALL VÄRLDENS LITTERATUR

NB

NORDISKA BOKHANDELN

Hörnet Drottninggat.-Fredsgat.
Postadress: Stockholm 1
Telefon: 23 84 00

GEOLOGISKA FÖRENINGENS I STOCKHOLM FÖRHANDLINGAR utkommer med 4 häften årligen (januari, mars, maj, november). Prenumeration mottages genom Nordiska bokhandeln, Stockholm 1, tel. 23 84 00 (växel).

Bd 1—31 à 20 kr.
» 32 » 60 »
» 33—65 » 20 »
» 66 » 30 »
» 67—69 » 20 »
» 70 » 25 »

Bd 71—73 à 20 kr.
» 74—78 » 30 »
» 79—80 » 40 »
Generalregister till
Bd 1—5 à 3 kr.
» 6—10 » 10 »
» 11—21 » 6 »

Generalregister till
Bd 22—31 à 6 kr.
» 32—41 » 6 »
» 42—50 » 6 »
» 51—60 » 6 »
» 61—70 » 10 »

Lösa häften av alla banden försäljs till pris beroende på häftenas omfång.

Medlemmar av Föreningen erhålla genom skattmästaren de äldre banden av Förhandlingarna och Generalregistret till hälften av det ovan upptagna bokhandelspriset. Å lösa häften lämnas ej prisnedsättning. (Styrelsens beslut d. $^{27}/_{10}$ 1922.)

Geologiska Föreningens sekreterare, Fil. Lic. Erik Åhman och redaktör, Docent P. H. Lundegårdh, träffas i Föreningens angelägenheter å Sveriges Geologiska Undersökning, tel. 34 97 90, säkrast tisdagar och torsdagar kl. 13—14.

Föreningens **ordinarie möten** äger rum första helgfria torsdag i månaderna februari, mars, april, maj, oktober, november och december. Januarimötet hålles på den torsdag, som infaller under tiden 10—16 jan. Anslag om föredragningslistan finns minst 3 dagar före sammanträdet uppsatta på anslagstavlorna å ett antal offentliga institutioner med geologisk anknytning i Stockholm, Uppsala och Lund.

Personlig kallelse till sammanträdena utfärdas till ledamöter, som så önskar, samt till dem, som är bosatta i Stockholmsområdet.

Uppsatser, avsedda att införas i Förhandlingarna, insänds till Föreningens redaktör, Stockholm 50. Åtföljande tavlor och figurer skall vara fullt färdiga till reproduktion, då de sänds jämte uppsatsen.

I Förhandlingarna må uppsatser införas antingen på skandinaviskt språk eller på engelska, franska eller tyska. Författare är skyldig att i det förra fallet bifoga översättning av titel och figurtexter samt abstract på engelska, franska eller tyska.

Manuskript, skrivet på främmande språk, skall vara granskat av sakkunnig språkman. Meddelande härom görs till redaktören.

Om korrektionskostnaderna för införd uppsats uppgår till mera än 24 kronor pr tryckark, är författare skyldig att erlägga det överskjutande beloppet, såvida det uppgår till minst 10 kr pr uppsats.

Författare erhåller gratis av införda uppsatser 100 separat i omslag med titel; ytterligare ex. betalas av förf. Av notiser, anmälanden och föredragsreferat lämnas separat endast efter särskild överenskommelse.

Referat honoreras sålunda (Fören. beslut $^{16}/_{1}$ 1958):
1 :sta sidan eller del därav efter 40 öre pr tryckrad, 2:dra sidan efter 30 och 3:dje sidan eller del därav efter 20 öre pr tryckrad. Följande sidor honoreras icke.

Anmälan om **föredrag och meddelanden** görs i god tid hos sekreteraren.

Ledamöternas årsavgifter, vilka enligt § 7 av Föreningens stadgar skall vara erlagda senast den 1 mars, inbetalas å postgiro 2108, Geologiska Föreningen, Stockholm 50, eller insänds till skattmästaren, Intendent O. Gabrielson, Stockholm 50, till vilken även lämnas uppgifter om ändring av adresser och titlar.

Årsavgiften utgör kr 25:—, avgift såsom ständig ledamot kr 300: — Ledamot, som under en följd av minst 20 år erlagt årlig ledamotsavgift, kan bli ständig ledamot mot en avgift av kr 150:—. Ledamot, som under 50 år erlagt årlig avgift, är befriad från ytterligare årsavgifter till Föreningen.

Postadress: Geologiska Föreningen, Stockholm 50. **Postgiro:** 2108. **Telefon.** 34 97 90.

INNEHÅLL

Contents

Uppsatser—Articles:

Möller, H.: Moränavlagringar med linser av sorterat material i Stockholmstrakten . . . 169
Tjernvik, T. E.: The Lower Didymograptus Shales of the Flagabro Drilling Core . . . 203
Nilsson, R.: A Preliminary Report on a Boring through Middle Ordovician Strata in Western Scania (Sweden) . . . 218
Assarsson, G. and Grundulis, V.: Enrichment of Organic Matter from Clays . . . 227
Gavelin, S.: On the Relations between Kinetometamorphism and Metasomatism in Granitization. Some Examples from the Archean of Eastern Sweden . . . 230
Bergström, L.: An Occurrence of Kyanite in a Pegmatite in Western Sweden . . . 270
Meddelande från Svenska föreningen för lerforskning . . . 273
Andersson, L.: Clay Chemistry in Soil Stabilization . . . 274
Höstmötet . . . 298
Marmo, V.: On the Granite and Spilitization . . . 299

Notis—Note:

Persson, P. O.: Morfologiska förändringar på Ivö i samband med »katastrofregnet» den 31 juli 1959 . . . 305

Recensioner—Reviews:

Lundegårdh, P. H.: Stenar i färg. Ref. av E. Åhman . . . 307
Korzhinski, D. S.: Physicochemical Basis of the Analysis of the Paragenesis of Minerals. Ref. av B. Lindqvist . . . 308
Jacobs, J. A., Russel, R. D. and Wilson, J. T.: Physics and Geology. Ref. av E. Welin 309
Simpson, G. G., Roe, A. and Lewontin, R. C.: Quantitative Zoology. Ref. av R. A. Reyment . . . 309
Behrmann, R. B.: Die geotektonische Entwicklung des Apennin-Systems. Ref. av G. Kautsky . . . 311

Mötesreferat—Proceedings: . . . 313
Geolognytt—Professional News: . . . 315

Författarna äro ensamma ansvariga för sina uppsatsers vetenskapliga innehåll.

Pris för detta häfte: 12:50 kronor

STOCKHOLM 1960. KUNGL. BOKTRYCKERIET P. A. NORSTEDT & SÖNER